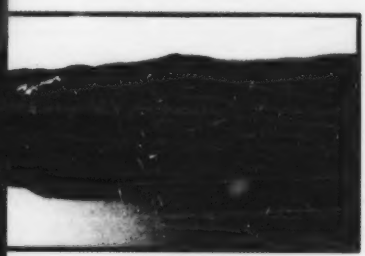
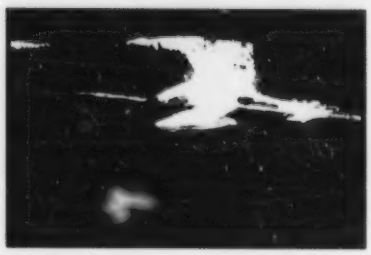
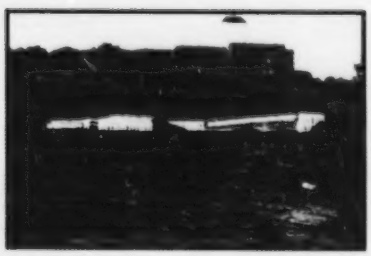
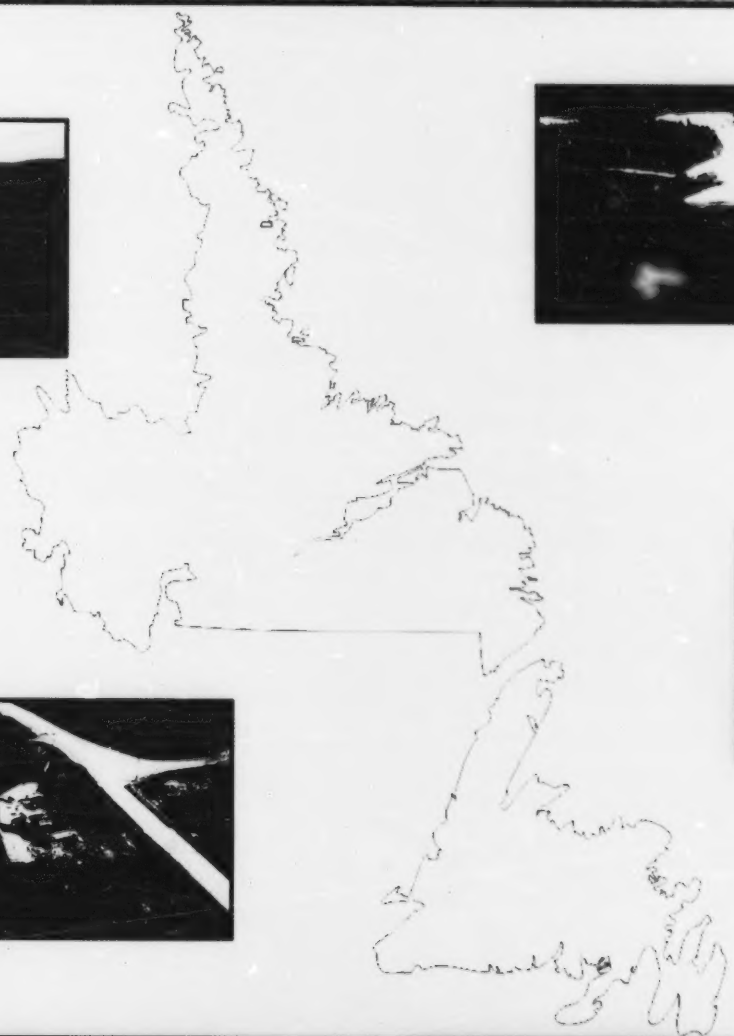
Standard Methods Guide

FOR THE CLASSIFICATION/QUANTIFICATION OF LACUSTRINE HABITAT IN NEWFOUNDLAND AND LABRADOR









The correct citation for this document is:

Bradbury, C., A.S. Power and M.M. Roberge. 2001. Standard Methods Guide for the Classification/Quantification of Lacustrine Habitat in Newfoundland and Labrador. Fisheries and Oceans, St. John's, NF. 60 p

Published by:

Fisheries and Oceans Canada
Science, Oceans and Environment Branch
P.O. Box 5667
St. John's, NF
A1C 5X1

[ISBN 0-662-31843-9]

Catalogue No. Fs 23-414/2002E

Printed in Canada on recycled paper

Printed by Stirling Press

102-05322/

Standard Methods Guide

For the Classification/
Quantification of Lacustrine Habitat
in Newfoundland and Labrador

by

C. Bradbury
A. S. Power
M. M. Roberge

Fisheries and Oceans Canada
Marine Environment and Habitat Management Division
Science, Oceans and Environment Branch
PO Box 5667
St. John's NF A1C 5X1

July 2001

TABLE OF CONTENTS

1.0 INTRODUCTION 4

1.1 The Project Review Process 4

1.2 Rationale for Proposed Methodology 6

1.3 Fish Habitat Requirements 6

1.4 Fish Species Inclusion 8

2.0 PROPOSED LACUSTRINE HABITAT CLASSIFICATION/ QUANTIFICATION METHODOLOGY 10

2.1 Area Habitat Estimates 13

2.2 Habitat Suitability Indices 17

2.3 Composite Habitat Suitability Indices 35

2.4 Habitat Equivalent Units 40

2.5 Summary 42

2.6 Partial Lake Destruction 43

3.0 ACKNOWLEDGMENTS 43

4.0 REFERENCES 43

APPENDIX A – Glossary of Terms 45

APPENDIX B - Field Methodologies 50

List of Figures

Figure 1.1: A flowchart illustrating the steps involved in DFO's project review process 5

Figure 2.1: A flowchart illustrating the steps involved in quantifying lacustrine habitat 11

Figure 2.2: Illustration depicting the littoral and non-littoral zones of a lake 12

Figure 2.3: Map of Lake X showing bathymetry and predominant substrate and cover types 17

List of Tables

Table 1.1: Listing of various fish species, including their different life stages, utilizing lacustrine habitat 9

Table 1.2: Listing of various fish species according to guild 9

Table 2.1: Listing of various fish species, including their different life stages, which are present within the lake 13

Table 2.2: Bottom surface area estimates of available lake habitat types. This information was obtained by conducting a detailed habitat survey of the lake 16

Table 2.3: Lacustrine habitat requirements data for brook trout (adapted from Table 17 of Bradbury et al. (1999)) 21

Table 2.4: Numerical values assigned to the subjective ratings reported for brook trout in Bradbury et al. (1999) 22

Tables 2.5: HSI calculations for depth x substrate combinations (i.e., *substrate/no vegetation* habitat categories) for all fish species, including their different life stages, which are present within the lake 23-28

Tables 2.6: HSI calculations for depth x substrate x vegetative cover combinations (i.e., *substrate/vegetation* habitat categories) for all fish species, including their different life stages, which are present within the lake 29-34

Table 2.7: Habitat Suitability Indices for all fish species, including their respective life stages, which are present within the lake 39

Table 2.8: Habitat Suitability Indices for each individual fish species present within the lake 40

Table 2.9: Habitat Equivalent Units for each individual fish species present within the lake. These units were calculated using the Habitat Suitability Indices reported in Table 2.8 and surface areas of available lake habitat types listed in Table 2.2 42

1.0 INTRODUCTION

1.1 The Project Review Process

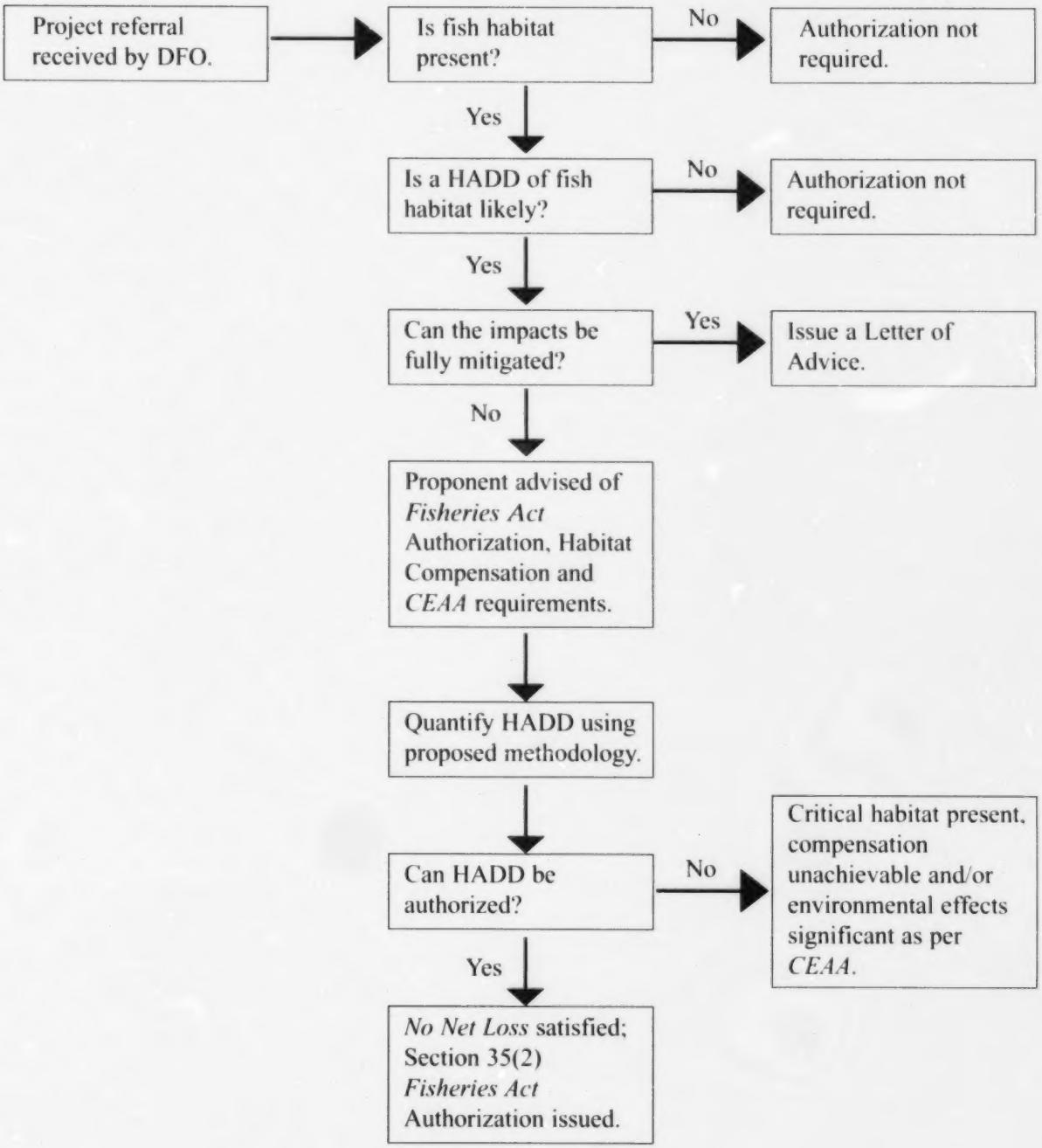
The Department of Fisheries and Oceans (DFO) is responsible for managing fish habitat in Newfoundland and Labrador and administering the habitat protection provisions of the *Fisheries Act*. Section 35(1) of the *Fisheries Act* prohibits the harmful alteration, disruption or destruction (HADD) of fish habitat unless it is authorized by the Minister of Fisheries and Oceans (i.e., issuance of a Section 35(2) *Fisheries Act* Authorization). The DFO defines HADD as '*any change in fish habitat that reduces its capacity to support one or more of the life processes of fish*' (Fisheries and Oceans Canada 1998a).

Although it is not mandatory to obtain a Section 35(2) *Fisheries Act* Authorization, anyone undertaking a project that results in a HADD of fish habitat and does not possess an Authorization is in violation of the *Fisheries Act* and may be prosecuted.

When issued, Section 35(2) *Fisheries Act* Authorizations are in keeping with the *No Net Loss* guiding principle of DFO's *Policy for the Management of Fish Habitat* (Fisheries and Oceans Canada 1986). Under this policy, DFO strives to balance unavoidable habitat losses with habitat replacement so that Canada's fisheries resources are not impacted. In order to satisfy these requirements DFO applies a hierarchy of preferences. The first step in applying the hierarchy is to avoid a HADD of fish habitat through project relocation or redesign. If a HADD is still likely to occur then the next step is to implement appropriate mitigations, such as rescheduling project timing, siltation control, provision of minimum flows, etc... (Fisheries and Oceans Canada 1998b).

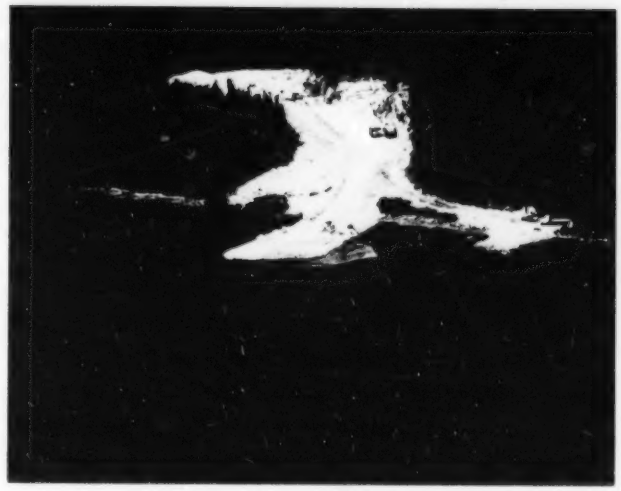
If it is determined that a HADD of fish habitat will occur after appropriate mitigative measures have been considered, the proponent will be advised that a Section 35(2) *Fisheries Act* Authorization will be required (Fig. 1.1). Issuance of an Authorization is conditional on the implementation of a plan by the proponent to compensate for any losses in productive fish habitat. It is important to note that Authorizations may not be issued in cases where compensation is inadequate to achieve *No Net Loss*, the loss of particular habitat types are considered critical or essential for the continued survival of a species or where species are considered to be at risk as per the proposed *Species at Risk Act* (SARA). Prior to issuing a Section 35(2) *Fisheries Act* Authorization, DFO must conduct an environmental assessment of the project in accordance with the *Canadian Environmental Assessment Act (CEAA)* (Fig. 1.1). For further information on the project review process and the relationship to *CEAA*, refer to Fisheries and Oceans Canada (1998a).

Figure 1.1: A flowchart illustrating the steps involved in DFO's project review process.


Project referral received by DFO.
Is fish habitat present?
No
Authorization not required.
Yes
Is a HADD of fish habitat likely?
No
Authorization not required.
Yes
Can the impacts be fully mitigated?
Yes
Issue a Letter of Advice.
No
Proponent advised of *Fisheries Act* Authorization, Habitat Compensation and *CEAA* requirements.
Quantify HADD using proposed methodology.
Can HADD be authorized?
No
Critical habitat present, compensation unachievable and/or environmental effects significant as per *CEAA*.
Yes
No Net Loss satisfied; Section 35(2) *Fisheries Act* Authorization issued.

1.2 Rationale for Proposed Methodology

The DFO and proponents realize that a repeatable, scientifically defensible methodology for the quantification of lacustrine fish habitat is necessary to assist with the implementation of DFO's *Policy for the Management of Fish Habitat* (Fisheries and Oceans Canada 1986). This document provides a standardized approach for conducting habitat assessments on all proposed developments impacting on lacustrine habitat (i.e., lakes, ponds) including HADD determination and compensation processes. This will aid proponents in developing project referrals as well as expedite the review of these referrals by habitat managers.



During road construction, siltation curtains are deployed to prevent harmful materials from entering fish habitat.

It is important to note that methodologies such as these are continually evolving and may be amended in the future. Revisions may be incorporated following feedback of user review, additional field testing/evaluation, as well as knowledge/experience acquired through project monitoring (e.g., environmental effects monitoring, compensation monitoring, etc.).

1.3 Fish Habitat Requirements

This methodology was originally inspired by some of the preliminary work reported by Dr. C.K. Minns (Minns 1995, 1997; Minns et al. 1995; Minns and Nairn 1999) and adapts some of the recommendations outlined in the Defensible Methods approach. Many of the basic concepts adopted in this lacustrine habitat classification/quantification approach have been based on Habitat Suitability Index (HSI) models that were developed by the U.S. Fish and Wildlife Service during the establishment of the Habitat Evaluation Procedures (HEP) (Terrell et al. 1982).

Freshwater habitat requirements of various fish species.

Recognizing that direct measures of fish productivity are often unavailable or too time consuming and costly to obtain, surrogates of productivity can be adopted such as HSI. The underlying premise of this approach is that the habitat requirements of various fish species and their different life stages can be quantified, thereby providing an index of habitat suitability, commonly referred to as HSI. These HSI values are based on measures that indicate species' habitat preferences/utilization and as such are used as surrogates of fish habitat productivity. A key assumption is the frequency a species utilizes a particular habitat provides a good indication of its importance to the species' well being and survival and as such the habitat's contribution to fish productivity. Thus, it can be inferred that decreasing a 'commonly used' or 'important' habitat will likely result in a reduction in productivity and conversely, increasing a similar habitat can result in an improvement in productivity.

Information on habitat use by various fish species and their different life stages is necessary for the effective management of fish and their habitat, in particular when assessing the potential impacts of various development activities. Information has been compiled on the habitat requirements/preferences of various life stages of freshwater and anadromous/catadromous fishes occurring throughout Newfoundland and Labrador (Bradbury et al. 1999).

Funding for this work was provided by the Great Lakes Laboratory of Fisheries and Aquatic Sciences (GLLFAS) in Burlington, Ontario and is being used to validate the applicability of a Defensible Methods approach, currently under development at the GLLFAS, to the Newfoundland Region. Emphasis was placed on the use of lake habitats by species during some portion of their life cycle. For most freshwater fish species, four distinct life stages were identified: i) spawning - individuals in spawning condition, ii) young-of-the-year (YOY) - individuals under one year of age, iii) juveniles - individuals older than one year of age, but not sexually mature, and iv) adults - individuals that have reached sexual maturity, but are not in spawning condition. It should be noted that a juvenile life stage was not assigned to species that become sexually mature during their first year of life since such species would move directly from YOY to adult. Preferences for the main physical habitat features including water depth, substrate type and cover were reported as nil (rarely associated), low (infrequently associated), medium (frequently associated) and high (nearly always associated).

Although certain conclusions regarding lacustrine habitat utilization can be drawn from Bradbury et al. (1999), some limitations do exist. Most importantly, the Newfoundland and Labrador studies reviewed rarely contained specific information on habitat utilization, therefore, much of the data compiled in this report was supplemented by studies from similar geographical areas within Canada, the United States and other countries in north temperate locations. Further, while there is a high probability that fish will utilize the habitats summarized by Bradbury et al. (1999), variations in prey availability, intra- and inter-specific competition, risk of predation, and changes in environmental variables may change local conditions. Hence, there is no assurance that the various fish species will occur in these areas at any given time. For instance, predator avoidance and competitive interactions between species often result in the movement of younger and smaller individuals to less preferred habitats. As another example, although upwelling groundwater appears to be an important determinant for brook trout spawning in most geographic areas, it is not always a prerequisite for spawning habitats in Newfoundland. This is probably because brook trout are more adaptive in their habitat utilization mainly due to a relative lack of predators and competitors. Other limitations listed in Bradbury et al. (1999) should also be consulted. These limitations notwithstanding, the data summarized in this report are useful in assessing the relative significance of different lake habitats in relation to the various life stages of freshwater fishes occurring in Newfoundland and Labrador.

1.4 Fish Species Inclusion

The Department recommends that the habitat requirements of all species found within a project area are considered in the classification/quantification of lacustrine habitat (Fisheries and Oceans Canada 1998a). This is relatively straightforward for projects in insular Newfoundland where the number of species is limited, however, in Labrador where species diversity is much higher, the task of considering every species is more challenging.

DFO may consider a guilding approach where it is impractical to consider all species present. A guild is defined as a group of species that have similar habitat and life history requirements. Consequently, these species will tend to be found together because they require similar environments. The species having the highest HSI value is generally chosen from each guild as a representative and only that species is evaluated. Typically, a list of all species present within the lake, including their different life stages, should be compiled (Table 1.1) prior to grouping any species in guilds (see Appendix B for information on fish sampling). In addition, a table outlining a complete list of species and how they are assigned to various guilds should be provided (Table 1.2). The rationale for assignment of various fish species to particular guilds should be explicitly stated (i.e., whether species were assigned on the basis of similar life history requirements or similar habitat requirements, or both).

Other options for determining which species to include in guilds also exist, but ecological rationale for species inclusion are typically preferable to other criteria that might be based on potential resource use such as the value of a particular fish species in supporting a commercial, recreational or aboriginal fishery. Proponents wishing to use different methods are encouraged to discuss their planned approach with DFO Habitat Management staff. It is important that any rationale used during this stage be explicitly stated and referenced with supporting documentation, where necessary.

Table 1.1: Listing of various fish species, including their different life stages, utilizing lacustrine habitat.

Species	Life Stages
	i) ii) iii) iv)
	i) ii) iii) iv)
	i) ii) iii) iv)
	i) ii) iii) iv)

Table 1.2: Listing of various fish species according to guild.

Guild	Species
	i) ii) iii) . .
	i) ii) iii) . .
	i) ii) iii) . .
	i) ii) iii) . .

2.0 PROPOSED LACUSTRINE HABITAT CLASSIFICATION/ QUANTIFICATION METHODOLOGY

For the purpose of this document, the classification and quantification of lacustrine habitat involves completing a series of tables, which facilitates the determination of available habitat within a lake or pond. A detailed step-by-step process has been developed to assist with the completion of the individual tables. For an overview of the steps involved see Fig. 2.1. In addition, a spreadsheet program is being developed to assist with performing the various calculations outlined in this document.

For this methodology, lacustrine habitat has been divided into two broad categories, namely the littoral and non-littoral zones (Fig. 2.2). The littoral zone is defined as the shallow, near shore region of a lake where adequate light can penetrate to the bottom allowing the growth of rooted aquatic plants. These peripheral areas are generally subject to fluctuating water temperatures and water levels as well as erosion of onshore materials through wave action and the grinding of ice.

The littoral zone is often considered the most productive region within a lake. This is partly related to the high nutrient inputs received from runoff of the surrounding land. Rooted vegetation and substrate heterogeneity also provide an abundance of habitats for many invertebrates and fish species that increases overall production. Typically, the littoral zone contains the greatest diversity and highest annual production of benthic organisms and may also contain important spawning, nursery, rearing and feeding habitat for many fish species.

The non-littoral zone is the central region of a lake that extends beyond the outer limit of the littoral zone and includes the littoriprofundal and profundal zones. It is characterized by the decay of, as opposed to, the production of organic matter. Substrates within this region are usually soft and offer little habitat diversity. According to Wetzel (1983), the littoriprofundal zone is a transitional zone below the littoral zone that is occupied by scattered photosynthetic algae and bacteria. The upper boundary of the littoriprofundal zone occurs at the lower edge of macrophytes, while the lower boundary consists of a gradient of benthic algae, especially blue-green algae and photosynthetic bacteria. The remainder of the sediments, which consist of exposed fine sediment free of vegetation that lies below the pelagic zone, is referred to as the profundal zone.

The pelagic zone refers to open-water regions of a lake that are not directly influenced by the shore or bottom. In this document, the pelagic component has been included in the quantification of non-littoral habitat, which represents habitat utilization that is not dependent on bottom substrate (see Section 2.3 for more details).

Figure 2.1: A flowchart illustrating the steps involved in quantifying lacustrine habitat.

STEP 1 - FISH SPECIES

Identify all fish species (including their different life stages) that are present within the project area.

If necessary, group species into guilds on the basis of similar habitat and/or life history requirements.

STEP 2 - HABITAT REQUIREMENTS INFORMATION

Consult Bradbury et al. (1999) (or other relevant information sources) for information on habitat requirements .

Compute HSIs for each species life stage. Note: If species are assigned to guilds, then a single HSI should be computed for each guild.

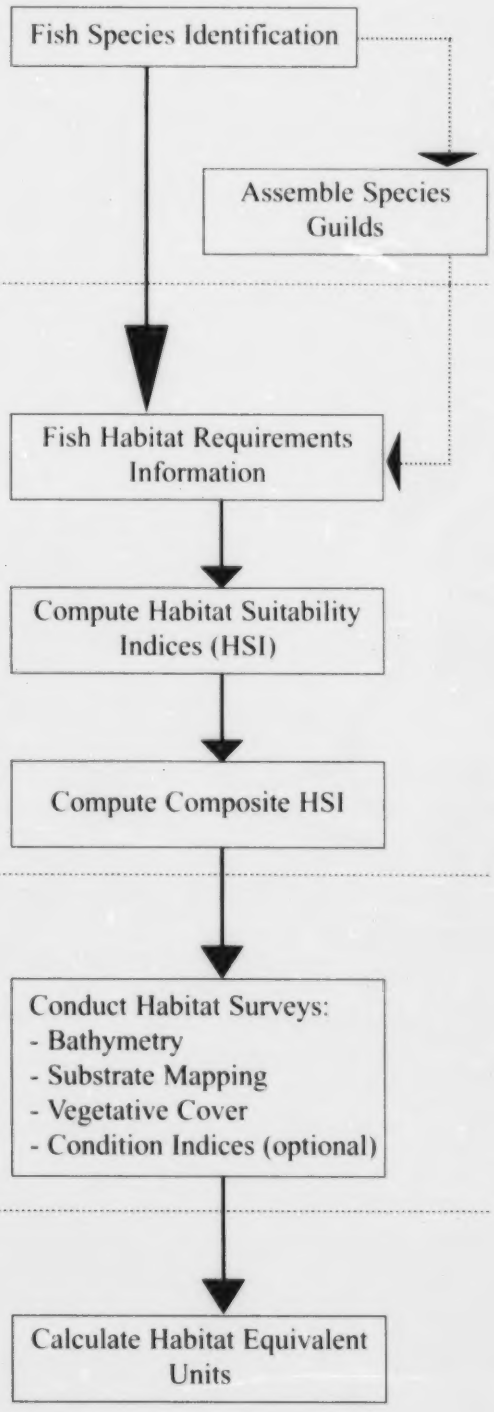
Compute composite HSIs for each species (or guild).

STEP 3 - HABITAT CHARACTERIZATION

Collect field data using the same categories reported in Bradbury et al. (1999). Classify available habitat types and report their total surface area.

STEP 4 - HABITAT EQUIVALENT UNITS

Calculate Habitat Equivalent Units which are simply measures of area multiplied by habitat suitability.



Note: ..... optional ——— mandatory

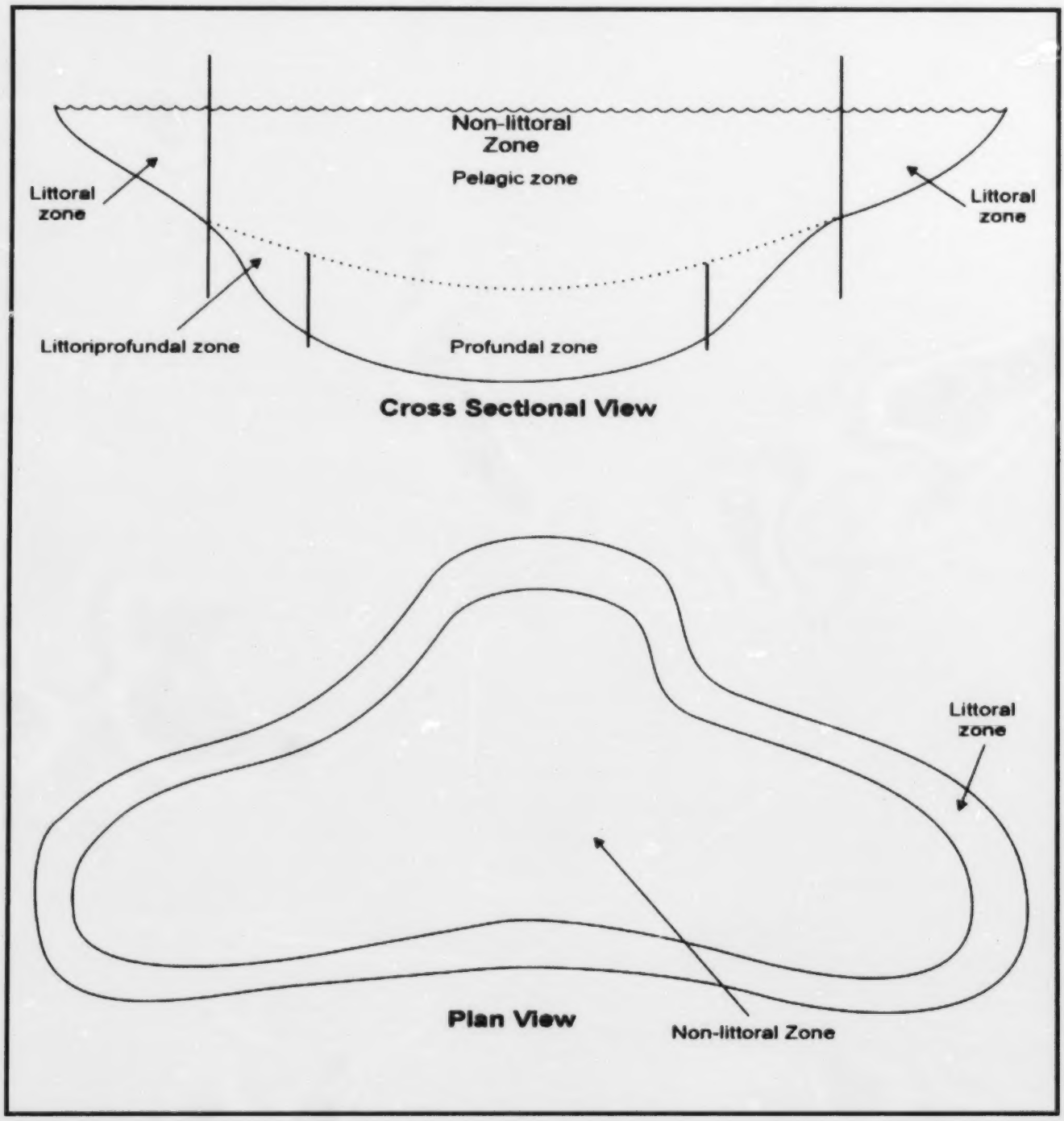


Figure 2.2: Illustration depicting the littoral and non-littoral zones of a lake.

2.1 Area Habitat Estimates

To follow is a step-by-step example of how the proposed methodology can be applied to quantify a HADD of fish habitat resulting from the destruction of an entire lake or pond.

Lake X is located in insular Newfoundland and contains anadromous Atlantic salmon and resident populations of brown trout, brook trout, rainbow smelt, American eel and threespine stickleback. Step 1 of Fig. 2.1 involves the identification of all fish species, including their different life stages, which are present within the lake. This information should be reported in Table 2.1 for consideration in the habitat classification/quantification process. Due to the relatively low species diversity within Lake X all individual species will be considered in the following calculations, rather than establishing guilds.

An open pit mine has been proposed and Lake X will be used for depositing tailings resulting from on-site processing. As such, the entire lake will be destroyed from a fish and fish habitat perspective.

Table 2.1: Listing of all fish species, including their different life stages, which are present within the lake.

Species	Life Stages
brook trout	i) spawning ii)YOY iii) juvenile iv) adult
Atlantic salmon (anadromous)	i) spawning ii)YOY iii) juvenile iv) adult
brown trout	i) spawning ii)YOY iii) juvenile iv) adult
rainbow smelt	i) spawning ii)YOY iii) juvenile iv) adult
threespine stickleback	i) spawning ii)YOY iii) juvenile iv) adult
American eel	i) spawning ii)YOY iii) juvenile iv) adult

Step 3 of Fig. 2.1 involves the collection of appropriate field data in order to characterize available habitat within the lake. This information should be reported in Table 2.2, following the instructions outlined below (Steps 1-4).

Step 1 Determine the extent of the littoral zone. A reasonable approximation of the extent of light penetration and hence the littoral zone may be obtained by measuring secchi depth. This estimate may be supplemented with information regarding the outer limit of plant growth and/or a delineation of the mud zone (i.e., the transition between coarse and fine substrate types). For the detailed methodology on how to measure secchi depth, refer to Appendix B.

Upon completion of the habitat survey, it was determined that the littoral zone extended to a depth of 2.0 m. As such, the values reported in the 0-1 and 1-2 m depth ranges should be included in the littoral zone calculations and those reported at depths greater than 2 m should be included in the non-littoral zone calculations.

Step 2 Bathymetric information should be collected and displayed as a bathymetric map. For information on appropriate contour intervals and suggested methodologies refer to Appendix B.

Step 3 **A)** Estimate the bottom surface area encompassed within the littoral zone. The bottom surface area of Lake X was determined to be 24.5 ha (or 244,765 m^2) with a littoral zone occupying 232,445 m^2 (Fig. 2.3). Determine the actual amount (m^2) of aquatic vegetation and substrate. Of interest are nine substrate types listed in the habitat requirements tables (Bradbury et al. 1999), as well as two categories of vegetative cover (submergent and emergent). It is important to note, however, that area habitat estimates only need to be calculated for habitat types (i.e., depths, substrates and vegetative cover types) that are actually present within a given lake. For instance, upon completion of the habitat survey, Lake X was found to contain only boulder, cobble, gravel, sand and muck substrates, therefore it is not necessary to include the other substrate types (bedrock, rubble, silt and clay listed in Bradbury et al. 1999) in any further calculations.

It is important to note that while information has been reported on cover types other than vegetation (e.g., overhead, *in situ*, etc.) in Bradbury et al. (1999), there is little evidence that habitat mapping is ever of sufficient detail in lacustrine environments to justify their inclusion. Despite this, additional cover types may be incorporated as knowledge on its use by local species becomes more available or if it is known that a certain type of cover is important during a particular stage of a fish's life history.

It should also be noted that vegetative cover need only be considered if it is utilized by at least one life stage of the species present. If none of the species utilize vegetation, then only the substrate underneath the vegetation should be included in the substrate mapping exercise. Refer to Appendix B for recommended methodology on substrate and vegetation mapping.

Mapping of the substrate and aquatic vegetation within Lake X produced the following information:

Littoral Zone

No Vegetation:

Substrate:	Coarse	Medium	Fine
	Bedrock - 0 m^2	Rubble - 0 m^2	Sand - 1,378 m^2
	Boulder - 11,279 m^2	Cobble - 50,351 m^2	Silt - 0 m^2
		Gravel - 9,844 m^2	Muck - 140,895 m^2
			Clay - 0 m^2
Totals:	**11,279 m^2**	**60,195 m^2**	**142,273 m^2**

Vegetation:

Substrate:	Coarse	Medium	Fine
	Bedrock - 0 m^2	Rubble - 0 m^2	Sand - 844 m^2
	Boulder - 465 m^2	Cobble - 5,404 m^2	Silt - 0 m^2
		Gravel - 2,944 m	Clay - 0 m^2
			Muck - 9,041 m^2
Totals:	**465 m^2**	**8,348 m^2**	**9,885 m^2**

B) Deduct the bottom surface area of the littoral zone from the total surface area of the lake to determine the bottom area of the non-littoral zone. The non-littoral zone of Lake X was determined to have an area of 12,320 m^2 (Fig. 2.3). Substrate mapping should also be conducted in the non-littoral zone, although it is likely that this will be a depositional area and substrate will consist mainly of fines. Since the maximum depth of the lake was estimated at 3.2 m, only the values in the 2-5 m depth range should be included in the non-littoral zone calculations. Values reported in the 5-10 and 10+ m ranges do not need to be included in the non-littoral zone calculations because these depths do not exist within the lake. Similarly, the only substrate identified within the non-littoral zone was muck. Therefore, only this substrate type should be included in any further calculations. Substrate mapping produced the following information:

Non-littoral Zone

Substrate	Coarse	Medium	Fine
	Bedrock - 0 m^2	Rubble - 0 m^2	Sand - 0 m^2
	Boulder - 0 m^2	Cobble - 0 m^2	Silt - 0 m^2
		Gravel - 0 m^2	Clay - 0 m^2
			Muck - 12,320 m^2
Totals:	**nil**	**nil**	**12,320 m^2**

Step 4 Having quantified all **available** substrates and vegetative cover types, add the quantities of appropriate substrate and vegetative cover types, where applicable to obtain estimates for each of the *substrate/no vegetation* and *substrate/vegetation* combinations (Table 2.2). For ease of presentation, substrate types may be categorized under three main headings: coarse (bedrock, boulder), medium (rubble, cobble and gravel), and fine (sand, silt, muck, and clay). In addition, submergent and emergent vegetation may be combined into a single category, vegetation. This will result in six main habitat categories within the littoral zone (coarse/no vegetation; medium/no vegetation; fine/no vegetation; coarse/vegetation; medium/vegetation; and fine/vegetation) and three main categories in the non-littoral zone (coarse/pelagic; medium/pelagic; and fine/pelagic).

To obtain the *littoral medium/no vegetation* habitat type, perform the following calculation: cobble/no vegetation + gravel/no vegetation; 50,351 m^2 + 9,844 m^2 = 60,195 m^2).

Table 2.2: Bottom surface area estimates of available lake habitat types. This information was obtained by conducting a detailed habitat survey of the lake.

Habitat Type	Bottom Surface Area (m^2)
Littoral Coarse/No Vegetation	11,279
Littoral Medium/No Vegetation	60,195
Littoral Fine/No Vegetation	142,273
Subtotal Littoral/No Vegetation	**213,747**
Littoral Coarse/Vegetation	465
Littoral Medium/Vegetation	8,348
Littoral Fine/Vegetation	9,885
Subtotal Littoral/Vegetation	**18,698**
Subtotal Littoral	**232,445**
Non-littoral Coarse/Pelagic	0
Non-littoral Medium/Pelagic	0
Non-littoral Fine/Pelagic	12,320
Subtotal Non-littoral	**12,320**
Total Available Habitat	**244,765**

Figure 2.3. Map of Lake X showing bathymetry and predominant substrate and cover types.

2.2 Habitat Suitability Indices

Step 2 of Fig. 2.1 involves determining the habitat requirements of the various fish species and their different life stages which are present within the lake. This may be accomplished by consulting Bradbury et al. (1999) and computing HSIs for each species life stage.

The tables that will be required will depend on the number of species and their respective life stages being considered in the habitat classification/quantification process. Similar to area habitat estimates, HSI values only need to be calculated for habitat types (i.e., depths, substrates and vegetative cover types) that are actually present within a given lake.

Note: Since the depth categories reported in the habitat preference tables of Bradbury et al. (1999) contain a range of values (0-1 m, 1-2 m, 2-5 m, etc.) it is likely that the measured littoral zone depth will occur somewhere in between these ranges. For the purpose of the following calculations, use the suitability indices that correspond to the upper limit of the depth range in which the littoral zone falls. For example, if the littoral zone depth is 7.0 m, the depth categories ranging from 0 - 10 m should be included within the littoral zone. Similarly, the depth category of 10+ m will correspond to the non-littoral zone.

For the purposes of this document, the non-littoral zone was subdivided into two unique zones; a benthic (or substrate dependent) zone and a pelagic (or open water) zone. The benthic zone is defined as extending 2 m upwards in the water column from the lake bottom, while the pelagic zone extends from the upper boundary of the benthic zone to the surface of the lake.

For non-littoral zone calculations, there are two recommended approaches depending on the mean depth of the lake.

For lakes having a mean depth of ≤10 m, *substrate/no vegetation* HSI values are calculated, summed with appropriate pelagic values reported in Bradbury et al. (1999) and the average of the two reported.

For lakes having a mean depth > 10 m, it is felt that the pelagic zone would likely represent a much greater proportion of the non-littoral zone than the benthic zone. Therefore, in order to ensure that the pelagic zone receives the appropriate representation, the relative proportion occupied by each respective zone should be determined and used to calculate HSI values.

Since the surface area of both the benthic and pelagic zones is the same (i.e., both extend across the entire non-littoral zone), the relative proportion occupied by each can be determined by reporting the ratio of the depth for both zones. For example, if the mean depth of the non-littoral zone measures 40 m, and the depth of the benthic zone has been defined as 2 m, then the benthic:pelagic ratio would be 2:40 (or 1:20). The *substrate/no vegetation* (or benthic) values and pelagic values are then multiplied by this corresponding ratio (i.e., *substrate/no vegetation* values are multiplied by 1 and pelagic values are multiplied by 20).

This concept could equally be applied to the littoral zone, however, it would only be meaningful where the depth of the littoral zone was considerably greater than the 2 m benthic zone. For most lakes in Newfoundland and Labrador, the littoral zone is typically < 5 m.

Step 1 For each species, assign numerical values to the subjective ratings reported in the habitat requirements tables contained in Bradbury et al. (1999) for each applicable depth, substrate and vegetative cover category. For illustrative purposes, the brook trout habitat requirements table contained in Bradbury et al. (1999) is provided (Table 2.3). Numerical values (referred to as HSI) must be assigned as follows: high - 1.00; medium - 0.67; low - 0.33; and nil - 0.00 (Table 2.4). Where no subjective ratings have been provided for substrate categories (i.e., during the literature search no information was found regarding utilization of a particular substrate type), assign a zero value. Where no subjective ratings have been provided for vegetative cover (i.e., during the literature search no information was found regarding utilization of a particular vegetative cover type), do not include it in the calculations. DFO decided to take this approach because although reporting on the utilization of substrates and water depths by various fish species appears to be fairly widespread and common in the literature, the same does not hold true for vegetative cover. Thus, an absence of information regarding the utilization of vegetative cover does not necessarily imply that it was not used by a particular species, rather it was not studied or reported in the literature.

Numerical values may be modified if supporting documentation is provided that is based on the results of scientifically sound field studies (i.e., based on site specific conditions supported by field observations, fish sampling, etc.) and/or recent findings in the literature.

Step 2 For the various depth categories within the lake (i.e., 0-1 m, 1-2 m and 2-5 m), HSIs have been summarized under two main categories; substrate having no vegetation (referred to as substrate/no vegetation) and substrate containing vegetation (referred to as substrate/vegetation).

A) For the *substrate/no vegetation* categories (i.e., Tables 2.5), calculate the average HSI for each depth and substrate combination (i.e., two-way combination of depth x substrate).

Note: The average will not be used in situations where no subjective rating has been reported, or if it is nil. If either of these two conditions occur, a zero will be assigned. This will prevent the erroneous inclusion or combination of habitat variables that inaccurately reflect habitat utilization. For example, a depth of 0-1 meters is given a high (1.0) for spawning brook trout, while bedrock is given a zero (0.0). It is unlikely that brook trout would utilize bedrock during spawning even if it were present at a depth at which they would normally spawn. As a result, averaging these indices to obtain a value of 0.5 would inaccurately reflect the potential for habitat utilization. Thus, rather than averaging, this combination of habitat variables is assigned a zero.

Calculating depth x substrate (i.e., *substrate/no vegetation*) HSI:

When calculating the average of each of the two littoral depth categories by each of the five available substrate categories, if either of the values equals 0.00, assign a zero.

The following calculations apply to the spawning life stage of brook trout. Spawning brook trout at a depth of 0-1 m has a value of 1.00 and boulder has a value of 0.00. Since one of the values is a zero, do not average. Instead, enter a 0.00 under the boulder row of column 0-1 m in Table 2.5 for the spawning life stage of brook trout.

Continuing with the calculations in Table 2.5:

Spawning brook trout at a depth of 0-1 m has a value of 1.00 and cobble has a value of 0.67. Add the two values together and determine the average (i.e., 1.00 + 0.67/2 = 0.84). Enter this value under the cobble row of column 0-1 m.
Spawning brook trout at a depth of 0-1 m has a value of 1.00 and gravel has a value of 1.00. Add the two values together and determine the average. Enter this value (1.00) under the gravel row of column 0-1 m.
Spawning brook trout at a depth of 0-1 m has a value of 1.00 and sand has a value of 0.67. Add the two values together and determine the average. Enter this value (0.84) under the sand row of column 0-1 m.
Spawning brook trout at a depth of 0-1 m has a value of 1.00 and muck has a value of 0.33. Add the two values together and determine the average. Enter this value (0.67) under the muck row of column 0-1 m.

B) For the *substrate/vegetation* categories (i.e., Tables 2.6), calculate the average HSI for each depth, substrate and vegetative cover combination (i.e., a three-way combination of depth x substrate x vegetative cover).

Both vegetative cover types should be combined into a single category using the following criteria;

- if a value is reported for both emergent and submergent vegetation, calculate the average; if only one vegetative cover type contains a value, then simply incorporate this value as reported; and

- if there are no values reported for either vegetative cover type, or there is no vegetative cover present in the lake, ignore the three-way combination (i.e., depth x substrate x vegetative cover) and simply calculate the two-way combination using depth and substrate as outlined above.

Calculating depth x substrate x vegetation (i.e., *substrate/vegetation*) HSI:

The following calculations apply to the YOY life stage of brook trout. When calculating the average of each of the two littoral depth categories by each of the five available substrate categories and two vegetative cover types if either the depth or substrate values equal zero, assign a zero, otherwise follow the previous criteria regarding vegetative cover. Since there are values reported for both emergent (1.00) and submergent (1.00) vegetation under the YOY life stage for brook trout, an average of the two vegetative cover types is taken. This value is then averaged with corresponding depth and substrate values (i.e., 1.00 for the 0-1 m depth and 1.00 for boulder). Add the three values together and determine the average (i.e., 1.00 + 1.00 + 1.00/3 = 1.00). Enter this value under the boulder row of column 0-1 m in Table 2.6 for the YOY life stage of brook trout.

Continuing with the calculations in Table 2.6:

YOY brook trout at a depth of 0-1 m has a value of 1.00, cobble has a value of 1.00 and vegetation has a value of 1.00. Add the three values together and determine the average (i.e., 1.00 + 1.00 + 1.00 = 3.00; 3.00/3 = 1.00). Enter this value under the cobble row of column 0-1 m.

YOY brook trout at a depth of 0-1 m has a value of 1.00, gravel has a value of 1.00 and vegetation has a value of 1.00. Add the three values together and determine the average. Enter this value (1.00) under the gravel row of column 0-1 m.

YOY brook trout at a depth of 0-1 m has a value of 1.00, sand has a value of 0.00 and vegetation has a value of 1.00. Since substrate has a zero value, do not average. Instead, enter a 0.00 under the sand row of column 0-1 m.

YOY brook trout at a depth of 0-1 m has a value of 1.00, muck has a value of 0.00 and vegetation has a value of 1.00. Since substrate has a value of zero, do not average. Instead, enter a 0.00 under the muck row of column 0-1 m.

Step 3 Complete a separate table for all life stages of each species under consideration.

Step 4 If species are assigned to guilds, compute a single HSI value for each guild. This should involve choosing the species (or life stage) with the highest HSI as being the representative.

Table 2.3: Lacustrine habitat requirements data for brook trout (adapted from Table 17 of Bradbury et al. (1999)).

Habitat Features	**Ratings[2]**			
Categories[1]	**S**	**Y**	**J**	**A**
Depths:				
0-1 meters	H	H	H	H
1-2 meters	H	H	H	H
2-5 meters	L	H	H	H
5-10 meters	L	L	M	M
10+ meters			M	M
Substrate:				
Bedrock				
Boulder		*H*	H	
Rubble	L	H	H	
Cobble	M	H	H	H
Gravel	H	H	H	H
Sand	M			L
Silt	L			L
Muck (detritus)	L			
Clay (mud)	L			
Pelagic			L	L
Cover:				
Submergents		H	H	
Emergents		H	H	H

[1]Categories are S-spawning, Y-young-of-the-year (YOY), J-juvenile and A-adult.
[2]Ratings are Nil, L-low, M-medium and H-high.

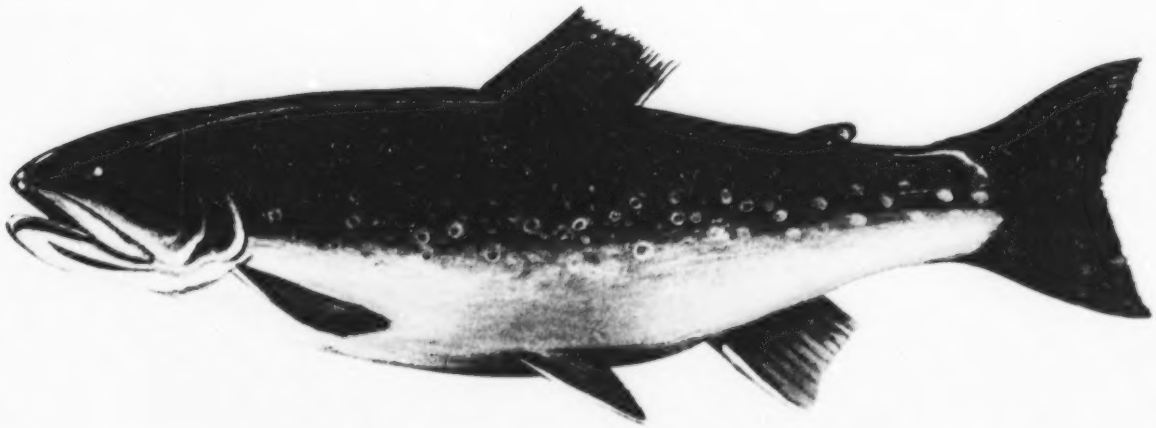
Note: Ratings that appear in *italics* represent instances where there was no information available on specific lake habitat utilization, so extrapolations were made based on known habitat requirements of similar life stages, information on diet or feeding and/or habitat use in riverine environments.

Table 2.4: Numerical values assigned to the subjective ratings reported for brook trout in Bradbury et al. (1999).

Habitat Features	**Ratings**			
Categories[1]	**S**	**Y**	**J**	**A**
Depths:				
0-1 meters	1.00	1.00	1.00	1.00
1-2 meters	1.00	1.00	1.00	1.00
2-5 meters	0.33	1.00	1.00	1.00
5-10 meters	0.33	0.33	0.67	0.67
10+ meters			0.67	0.67
Substrate:				
Bedrock				
Boulder		*1.00*	1.00	
Rubble	0.33	1.00	1.00	
Cobble	0.67	1.00	1.00	1.00
Gravel	1.00	1.00	1.00	1.00
Sand	0.67			0.33
Silt	0.33			0.33
Muck (detritus)	0.33			
Clay (mud)	0.33			
Pelagic			0.33	0.33
Cover:				
Submergents		1.00	1.00	
Emergents		1.00	1.00	1.00

[1]Categories are S-spawning, Y-young-of-the-year (YOY), J-juvenile and A-adult.

Tables 2.5: HSI calculations for depth x substrate combinations (i.e., *substrate/no vegetation* habitat categories) for all fish species, including their different life stages, which are present within the lake.



Species: brook trout - adapted from Table 17 of Bradbury et al. (1999)

Life Stage: spawning

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.84	0.84	NA
Gravel	1.00	1.00	NA
Sand	0.84	0.84	NA
Muck	0.67	0.67	0.33
Pelagic	0.00		

Life Stage: YOY

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: juvenile

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.33		

Life Stage: adult

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	0.67	0.67	NA
Muck	0.00	0.00	0.00
Pelagic	0.33		

Species: Atlantic salmon (anadromous) - adapted from Table 15 of Bradbury et al. (1999)

Life Stage: spawning

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: YOY

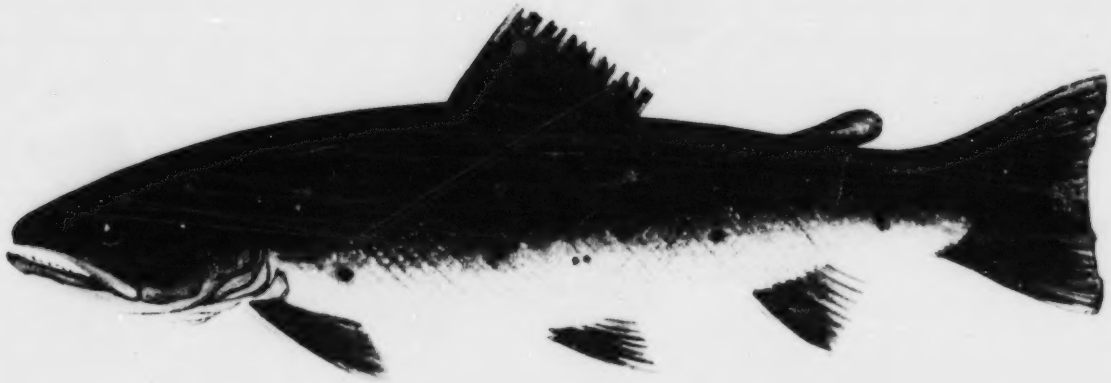
Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	0.67	0.67	NA
Sand	0.67	0.67	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: juvenile

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	0.84	0.84	NA
Sand	0.67	0.67	NA
Muck	0.00	0.00	0.00
Pelagic	0.50		

Life Stage: adult

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		



Species: brown trout - adapted from Table 18 of Bradbury et al. (1999)

Life Stage: spawning

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: YOY

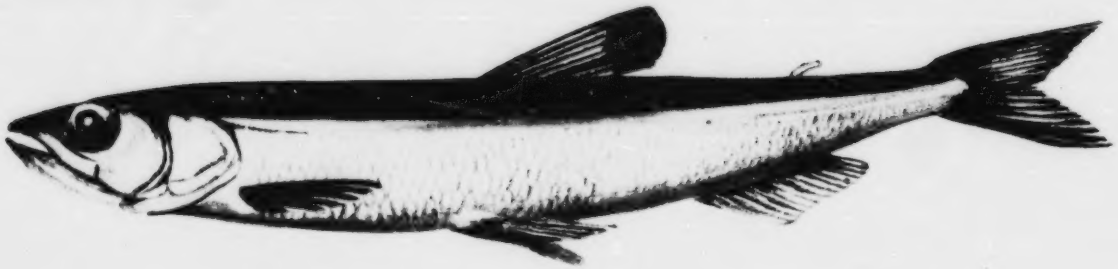
Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	0.84	0.84	NA
Sand	0.84	0.84	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: juvenile

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	0.84	0.84	NA
Sand	0.84	0.84	NA
Muck	0.00	0.00	0.00
Pelagic	0.33		

Life Stage: adult

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.67	0.67	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.50	0.50	0.50
Pelagic	0.67		



Species: rainbow smelt - adapted from Table 25 of Bradbury et al. (1999)

Life Stage: spawning

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	1.00	1.00	NA
Muck	1.00	1.00	1.00
Pelagic	1.00		

Life Stage: YOY

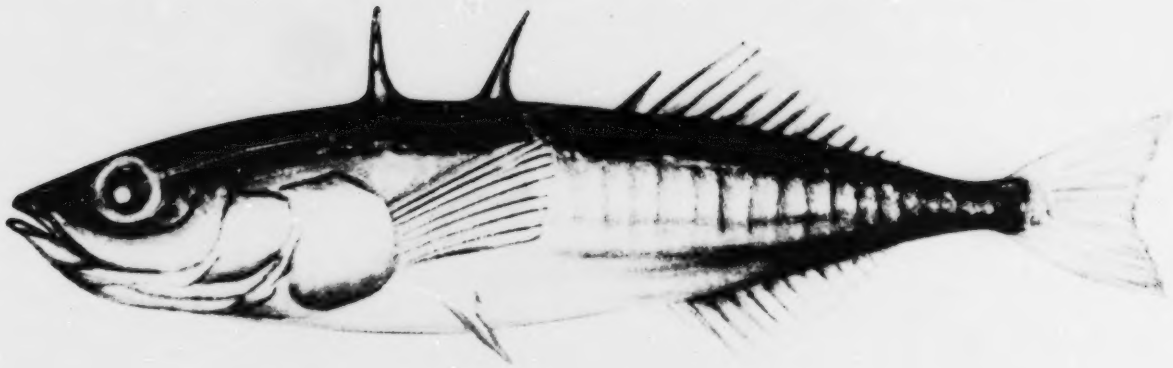
Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	1.00		

Life Stage: juvenile

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	1.00		

Life Stage: adult

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	1.00		



Species: threespine stickleback - adapted from Table 28 of Bradbury et al. (1999)

Life Stage: spawning

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.67	0.67	NA
Gravel	0.67	0.67	NA
Sand	1.00	1.00	NA
Muck	1.00	1.00	0.67
Pelagic	0.00		

Life Stage: YOY

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: juvenile

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: adult

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.67	0.67	NA
Gravel	0.67	0.67	NA
Sand	0.67	0.67	NA
Muck	1.00	1.00	1.00
Pelagic	1.00		

Species: American eel - adapted from Table 3 of Bradbury et al. (1999)

Life Stage: spawning

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: YOY

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Note: Since spawning occurs at sea and young typically spend their first year of life at sea before returning to fresh water, there is no lake habitat utilization during either of these two life stages.

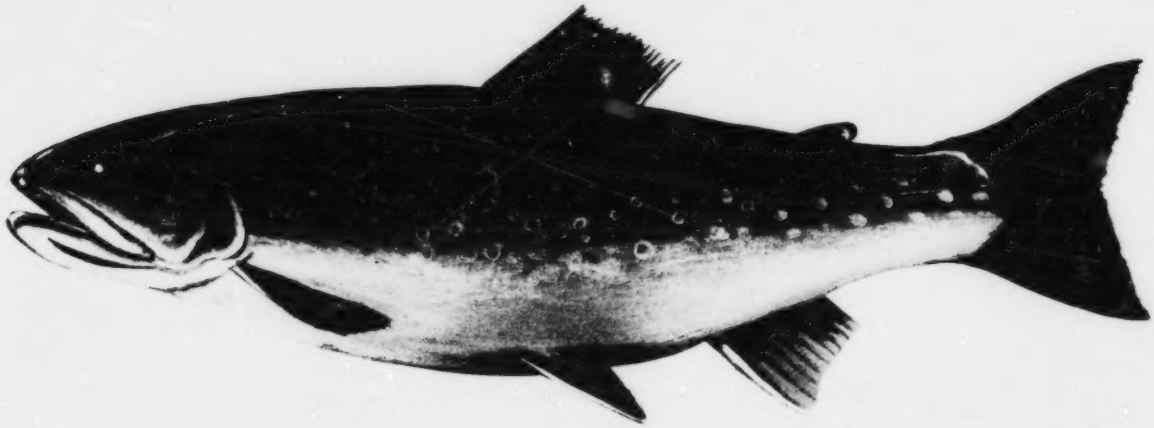
Life Stage: juvenile

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: adult

Substrate	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	1.00	1.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Tables 2.6: HSI calculations for depth x substrate x vegetative cover combinations (i.e., *substrate/ vegetation* habitat categories) for all fish species, including their different life stages, which are present within the lake.



Species: brook trout - adapted from Table 17 of Bradbury et al. (1999)

Life Stage: spawning

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.84	0.84	NA
Gravel	1.00	1.00	NA
Sand	0.84	0.84	NA
Muck	0.67	0.67	0.33
Pelagic	0.00		

Life Stage: YOY

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	[illegible]	1.00	NA
Cobble	[illegible]	1.00	NA
Gravel	[illegible]	1.00	NA
Sand	[illegible]	0.00	NA
Muck	[illegible]	0.00	0.00
Pelagic	0.00		

Life Stage: juvenile

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.33		

Life Stage: adult

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	0.78	0.78	NA
Muck	0.00	0.00	0.00
Pelagic	0.33		

Species: Atlantic salmon (anadromous) - adapted from Table 15 of Bradbury et al. (1999)

Life Stage: spawning

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: YOY

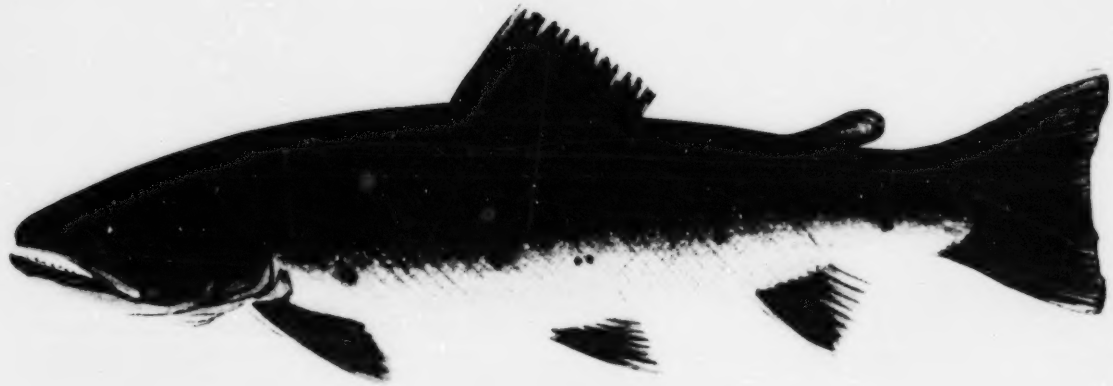
Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	0.67	0.67	NA
Sand	0.67	0.67	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: juvenile

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.78	0.78	NA
Cobble	0.78	0.78	NA
Gravel	0.67	0.67	NA
Sand	0.56	0.56	NA
Muck	0.00	0.00	0.00
Pelagic	0.50		

Life Stage: adult

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		



Species: brown trout - adapted from Table 18 of Bradbury et al. (1999)

Life Stage: spawning

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: YOY

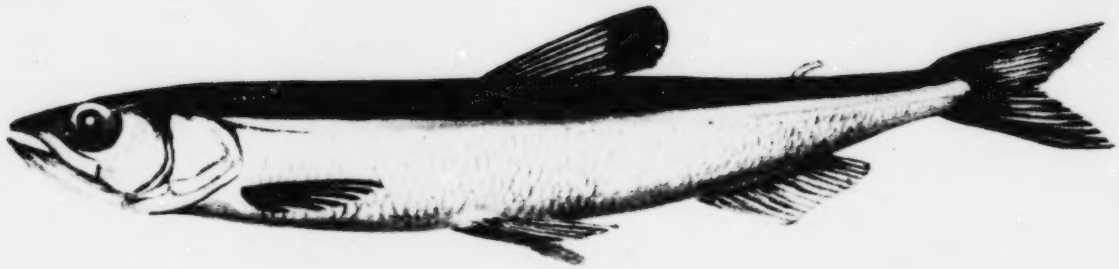
Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.78	0.78	NA
Cobble	0.78	0.78	NA
Gravel	0.67	0.67	NA
Sand	0.67	0.67	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: juvenile

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.78	0.78	NA
Cobble	0.78	0.78	NA
Gravel	0.67	0.67	NA
Sand	0.67	0.67	NA
Muck	0.00	0.00	0.00
Pelagic	0.33		

Life Stage: adult

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.67	0.67	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.50	0.50	0.50
Pelagic	0.67		



Species: rainbow smelt - adapted from Table 25 of Bradbury et al. (1999)

Life Stage: spawning

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	1.00	1.00	NA
Sand	1.00	1.00	NA
Muck	1.00	1.00	1.00
Pelagic	1.00		

Life Stage: YOY

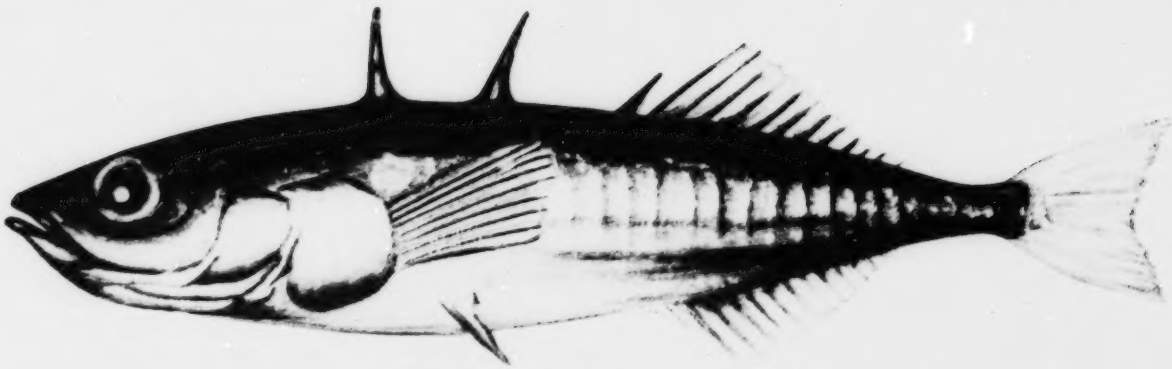
Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	1.00	1.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	1.00		

Life Stage: juvenile

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	1.00		

Life Stage: adult

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	1.00		



Species: threespine stickleback - adapted from Table 28 of Bradbury et al. (1999)

Life Stage: spawning

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.67	0.67	NA
Gravel	0.67	0.67	NA
Sand	0.89	0.89	NA
Muck	0.89	0.89	0.67
Pelagic	0.00		

Life Stage: YOY

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: juvenile

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: adult

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.78	0.78	NA
Gravel	0.78	0.78	NA
Sand	0.78	0.78	NA
Muck	1.00	1.00	1.00
Pelagic	1.00		

Species: American eel - adapted from Table 3 of Bradbury et al. (1999)

Life Stage: spawning

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: YOY

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.00	0.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Note: Since spawning occurs at sea and young typically spend their first year of life at sea before returning to fresh water, there is no lake habitat utilization during either of these two life stages.

Life Stage: juvenile

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	0.78	0.78	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	0.00	0.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

Life Stage: adult

Substrate/ Cover	Depth (m)		
	0-1	1-2	2-5
Boulder	1.00	1.00	NA
Cobble	0.00	0.00	NA
Gravel	0.00	0.00	NA
Sand	1.00	1.00	NA
Muck	0.00	0.00	0.00
Pelagic	0.00		

2.3 Composite Habitat Suitability Indices

Step 2 of Fig. 2.1 involves calculating a composite HSI for each species that is representative of the habitat requirements of all its individual life stages. This information should be reported in Tables 2.7 and 2.8 by following the instructions (Steps 1-10) below, where applicable.

Step 1 Using Tables 2.5, calculate the *littoral coarse/no vegetation* composite HSI for each life stage of all species. To accomplish this, average the HSI values for bedrock and boulder that correspond to the determined littoral zone depth range. If substrate mapping indicates that there are no coarse substrates in the littoral zone, this step may be omitted from the calculations.

Step 2 Using Tables 2.5, calculate the *littoral medium/no vegetation* composite HSI for each life stage of all species. To accomplish this, average the HSI values for rubble, cobble and gravel that correspond to the determined littoral zone depth range. If substrate mapping indicates that there are no medium substrates in the littoral zone, this step may be omitted from the calculations.

Step 3 Using Tables 2.5, calculate the *littoral fine/no vegetation* composite HSI for each life stage of all species. To accomplish this, average the HSI values for sand, silt, muck and clay that correspond to the determined littoral zone depth range. If substrate mapping indicates that there are no fine substrates in the littoral zone, this step may be omitted from the calculations.

To determine the HSI for the adult life stage of brook trout, conduct the following calculations.

Calculating composite depth x substrate (i.e., *substrate/no vegetation*) HSI within the littoral zone:

For *littoral coarse/no vegetation* habitat, average the HSI values reported in Table 2.5 for coarse substrate (only boulder in this instance since no bedrock was identified in the lake) that correspond to the determined littoral zone depth range (2 m). The value for boulder at 0-1 m depth is 0.00 and the value for boulder at 1-2 m depth is also 0.00. Since both values are zero, enter a 0.00 in the *littoral coarse/no vegetation* column in Table 2.7.

Continuing with the calculations:

For *littoral medium/no vegetation* habitat, average the HSI values reported in Table 2.5 for medium substrate (only cobble and gravel in this instance since no rubble was identified in the lake) that correspond to the determined littoral zone depth range (2 m). The values for cobble and gravel at 0-1 m depth are both 1.00 as are the values for cobble and gravel at 1-2 m depth. The average of these four values is 1.00. Enter this value in the *littoral medium/no vegetation* column in Table 2.7.

For *littoral fine/no vegetation* habitat, average the HSI values reported in Table 2.5 for fine substrate (only sand and muck in this instance since no silt or clay were identified in the lake) that correspond to the determined littoral zone depth range (2 m). The values for sand and muck are 0.67 and 0.00, respectively for both the 0-1 m and 1-2 m depth. The average of these four values is 0.34 (i.e., 0.67 + 0.00 + 0.67 + 0.00/4 = 0.34). Enter this value in the *littoral fine/no vegetation* column in Table 2.7.

Step 4 Using Tables 2.6, calculate the *littoral coarse/vegetation* composite HSI for each life stage of all species. To accomplish this, average the HSI values for bedrock and boulder that correspond to the determined littoral zone depth range. If substrate mapping indicates that there are no coarse substrates in the littoral zone, this step may be omitted from the calculations. In addition, if there is no vegetative cover present within the littoral zone, or if neither species being considered utilizes vegetation for cover, this step may be omitted from the calculations.

Step 5 Using Tables 2.6, calculate the *littoral medium/vegetation* composite HSI for each life stage of all species. To accomplish this, average the HSI values for rubble, cobble and gravel that correspond to the determined littoral zone depth range. If substrate mapping indicates that there are no medium substrates in the littoral zone, this step may be omitted from the calculations. In addition, as mentioned previously, if there is no vegetative cover present within the littoral zone, or if neither of the species being considered utilize vegetation for cover, this step may be omitted from the calculations.

Step 6 Using Tables 2.6, calculate the *littoral fine/vegetation* composite HSI for each life stage of all species. To accomplish this, average the HSI values for sand, silt, muck and clay that correspond to the determined littoral zone depth range. If substrate mapping indicates that there are no fine substrates in the littoral zone, this step may be omitted from the calculations. In addition, if there is no vegetative cover present within the littoral zone, or if neither species being considered utilizes vegetation as cover, this step may be omitted from the calculations.

To determine the HSI for the adult life stage of brook trout, conduct the following calculations.

Calculating composite depth x substrate x vegetation (i.e., *substrate/vegetation*) HSI within the littoral zone:

For *littoral coarse/vegetation* habitat, average the HSI values reported in Table 2.6 for coarse substrate (only boulder in this instance since no bedrock was identified in the lake) that correspond to the determined littoral zone depth range (2 m). The values for boulder at 0-1 m and 1-2 m depths are both 0.00. Since both values are zero, enter a 0.00 in the *littoral coarse/vegetation* column in Table 2.7.

For *littoral medium/vegetation* habitat, average the HSI values reported in Table 2.6 for medium substrate (only cobble and gravel in this instance since no rubble was identified in the lake) that correspond to the determined littoral zone depth range (2 m). The values for cobble and gravel at 0-1 m and 1-2 m depth are all 1.00, therefore the average of these four values is also 1.00. Enter this value in the *littoral medium/vegetation* column in Table 2.7.

For *littoral fine/vegetation* habitat, average the HSI values reported in Table 2.6 for fine substrate (only sand and muck in this instance since no silt or clay were identified in the lake) that correspond to the determined littoral zone depth range (2 m). The values for sand and muck are 0.78 and 0.00, respectively for both the 0-1 m and 1-2 m depth. The average of these four values is 0.39 (i.e., 0.78 + 0.00 + 0.78 + 0.00/4 = 0.39). Enter this value in the *littoral fine/vegetation* column in Table 2.7.

Step 7 Using Tables 2.5, calculate the *non-littoral coarse/pelagic* composite HSI for each life stage of all species. To accomplish this, average the HSI values for bedrock and boulder that correspond to the determined non-littoral zone depth range. If mean depth of lake ≤10 m, then sum this value with the life stage specific pelagic suitability index reported in Bradbury et al. (1999) and determine the average. If mean depth of lake > 10 m, then calculate benthic: pelagic ratio as described on page 18. If substrate mapping indicates that there are no coarse substrates in the non-littoral zone, this step may be omitted from the calculations.

Step 8 Using Tables 2.5, calculate the *non-littoral medium/pelagic* composite HSI for each life stage of all species. To accomplish this, average the HSI values for rubble, cobble, and gravel that correspond to the determined non-littoral zone depth range. If mean depth of lake ≤10 m, then sum this value with the life stage specific pelagic suitability index found in Bradbury et al. (1999) and determine the average. If mean depth of lake > 10 m, then calculate benthic: pelagic ratio as described on page 18. If substrate mapping indicates that there are no medium substrates in the non-littoral zone, this step may be omitted from the calculations.

Step 9 Using Tables 2.5, calculate the *non-littoral fine/pelagic* composite HSI for each life stage of all species. To accomplish this, average the HSI values for sand, silt, muck, and clay that correspond to the determined non-littoral zone depth range. If mean depth of lake ≤10 m, then sum this value with the life stage specific pelagic suitability index reported in Bradbury et al. (1999) and determine the average. If mean depth of lake > 10 m, then calculate benthic: pelagic ratio as described on page 18. If substrate mapping indicates that there are no fine substrates in the non-littoral zone, this step may be omitted from the calculations.

To determine the HSI for the adult life stage of brook trout, conduct the following calculations.

Calculating composite substrate/pelagic HSI within the non-littoral zone:

It should be noted that the mean depth of the lake is ≤10 m, therefore the pelagic value is simply averaged with the *substrate/no vegetation* HSI.

For *non-littoral coarse/pelagic* habitat since there are no coarse substrates (boulder or bedrock) present within the non-littoral zone (2-5 m depth), assign a \ \ to the *non-littoral coarse/pelagic* column in Table 2.7.

For *non-littoral medium/pelagic* habitat since there are no medium substrates (cobble, gravel or rubble) present within the non-littoral zone (2-5 m depth), assign a \ \ to the *non-littoral medium/pelagic* column in Table 2.7.

For *non-littoral fine/pelagic* habitat, average the HSI values reported in Table 2.5 for fine substrate (muck only in this instance since no sand, silt or clay were identified in the lake) that correspond to the non-littoral zone depth range (2-5 m). The value for muck is 0.00 at the 2-5 m depth and the value for pelagic is 0.33. The average of these two values is 0.17. Enter this value in the *non-littoral fine/pelagic* column in Table 2.7.

Step 10 To complete Table 2.8, refer to the composite HSI values reported in Table 2.7 and for each individual species, choose the highest composite HSI across all life stages for each of the nine main habitat categories.

Due to the general paucity of information regarding regional lake habitat requirements for various fish species and the effects of habitat alteration/disruption on fish populations, DFO decided that a precautionary approach was warranted which supports the notion that one should be more cautious when information is uncertain, unreliable or inadequate (Richards and Maguire 1998). As such, the highest rating across all life stages of each individual species should be reported in Table 2.8 for each habitat type. This approach was taken to ensure that critical habitat requirements for all life stages and species would be maintained. Further justification lies in the experimental nature of achieving compensation for habitat loss (i.e., time period required for productive habitat to be developed or re-established).

Table 2.7: Habitat Suitability Indices for all fish species, including their respective life stages, which are present within the lake.

		Littoral Zone						Non-littoral Zone		
Species	**Life Stage**	Coarse/No Vegetation (boulder)	Medium/No Vegetation (cobble & gravel)	Fine/No Vegetation (sand & muck)	Coarse/Vegetation (boulder)	Medium/Vegetation (cobble & gravel)	Fine/Vegetation (sand & muck)	Coarse/Pelagic	Medium/Pelagic	Fine/Pelagic (muck)
brook trout	Spawning	0.00	0.92	0.76	0.00	0.92	0.76	NA	NA	0.17
	YOY	1.00	1.00	0.00	1.00	1.00	0.00			0.00
	Juvenile	1.00	1.00	0.00	1.00	1.00	0.00			0.17
	Adult	0.00	1.00	0.34	0.00	1.00	0.59			0.17
Atlantic salmon	Spawning	0.00	0.00	0.00	0.00	0.00	0.00	NA	NA	0.00
	YOY	1.00	0.84	0.34	1.00	0.84	0.34			0.00
	Juvenile	1.00	0.92	0.34	0.78	0.73	0.28			0.25
	Adult	0.00	0.00	0.00	0.00	0.00	0.00			0.00
brown trout	spawning	0.00	1.00	0.00	0.00	1.00	0.00	NA	NA	0.00
	YOY	1.00	0.92	0.42	0.78	0.73	0.34			0.00
	Juvenile	1.00	0.92	0.42	0.78	0.73	0.34			0.17
	Adult	0.67	0.00	0.25	0.67	0.00	0.25			0.59
rainbow smelt	Spawning	1.00	1.00	1.00	1.00	1.00	1.00	NA	NA	1.00
	YOY	1.00	0.50	0.00	1.00	0.50	0.00			0.50
	Juvenile	0.00	0.00	0.00	0.00	0.00	0.00			0.50
	Adult	0.00	0.00	0.00	0.00	0.00	0.00			0.50
threespine stickleback	Spawning	0.00	0.67	1.00	0.00	0.67	0.89	NA	NA	0.34
	YOY	0.00	0.00	0.00	0.00	0.00	0.00			0.00
	Juvenile	0.00	0.00	0.00	0.00	0.00	0.00			0.00
	Adult	0.00	0.67	0.84	0.00	0.78	0.89			1.00
American eel	Spawning	0.00	0.00	0.00	0.00	0.00	0.00	NA	NA	0.00
	YOY	0.00	0.00	0.00	0.00	0.00	0.00			0.00
	Juvenile	1.00	0.00	0.00	0.78	0.00	0.00			0.00
	Adult	1.00	0.00	0.50	1.00	0.00	0.50			0.00

Note: A single habitat type (e.g., *littoral coarse/no vegetation, littoral medium/no vegetation, littoral fine/no vegetation*, etc.) may have a range of suitability values attached to it, representing different fish species (i.e., the suitability for a particular habitat type may be high for one species and low for another).

NA – Habitat type does not exist within the lake in question.

Table 2.8: Habitat Suitability Indices for each individual fish species present within the lake.

	Littoral Zone						Non-littoral Zone		
Species	Coarse/No Vegetation (boulder)	Medium/No Vegetation (cobble & gravel)	Fine/No Vegetation (sand & muck)	Coarse/Vegetation (boulder)	Medium/Vegetation (cobble & gravel)	Fine/Vegetation (sand & muck)	Coarse/Pelagic	Medium/Pelagic	Fine/Pelagic (muck)
brook trout	1.00	1.00	0.76	1.00	1.00	0.76	NA	NA	0.17
Atlantic salmon	1.00	0.92	0.34	1.00	0.84	0.34	NA	NA	0.25
brown trout	1.00	1.00	0.42	0.78	1.00	0.34	NA	NA	0.59
rainbow smelt	1.00	1.00	1.00	1.00	1.00	1.00	NA	NA	1.00
threespine stickleback	0.00	0.67	1.00	0.00	0.78	0.89	NA	NA	1.00
American eel	1.00	0.00	0.50	1.00	0.00	0.50	NA	NA	0.00

Note: Reported values represent the highest rating across all life stages of a particular species.

NA – Habitat type does not exist within the lake in question.

2.4 Habitat Equivalent Units

Step 4 of Fig. 2.1 involves calculating habitat equivalent units, which relate a habitat's suitability to the amount of that habitat available within a lake or pond. This information should be reported in Table 2.9 by following the instructions (Steps 1-3) outlined below.

Step 1 Refer to Table 2.2 to obtain values for the actual surface area (m^2) of each available habitat type.

Step 2 Refer to Table 2.8 to obtain composite HSI values for each individual fish species.

Step 3 To calculate the habitat equivalent units for each individual fish species, multiply the composite HSI by the corresponding surface area of each available habitat type. The resultant values provide a relative measure of fish habitat productivity. Habitat equivalent units also provide a basis for determining the amount of habitat expected to be harmfully altered, disrupted or destroyed as a result of development activities. In addition, it may be used in discussions related to fish habitat compensation.

Thus, a single habitat type may have a range of suitability values attached to it, representing its utilization by different fish species or guilds (i.e., suitability/utilization of a particular habitat type may be high for one fish species or guild and low for another).

To determine the habitat equivalent units for brook trout, *littoral coarse/no vegetation* habitat type, perform the following calculations:

Consult Table 2.2 to determine the actual surface area of *littoral coarse/no vegetation* habitat present within the lake (11,279 m^2).

Next consult Table 2.8 and identify the brook trout composite HSI for *littoral coarse/no vegetation* (1.00).

Finally, to ascertain the Habitat Equivalent Units multiply the composite HSI for *littoral coarse/no vegetation* by the surface area of available *littoral coarse/no vegetation* habitat (i.e., 1.00 x 11,279 m^2 = 11,279 m). Enter this value in Table 2.9. The end result (i.e., product of area and suitability) is a measurement that can be used to determine the HADD of fish habitat.

Step 4 Indirect measures of lake condition, commonly referred to as condition indices, may also be incorporated in the habitat quantification process as a means of reflecting impacts of other habitat variables on fish habitat productivity. Condition indices may include such measures as nutrient availability, water quality parameters, lake morphometry, presence of contaminants, etc. Condition indices should be scaled between 0 and 1 and careful consideration must be given when selecting these indices since the factors affecting habitat quality or productivity often vary from one lake to another.

Water quality requirements of various fish species.

Although it is important to exercise caution when applying such condition indices, their use and any resultant adjustments to productivity could prove to be extremely useful, especially when assessing already degraded or highly productive habitats. For instance, condition indices provide a safeguard against the loss of highly productive habitat or over-compensation of extremely unproductive habitat.

If condition indices are to be included in the habitat quantification process, proponents must discuss with DFO and ensure that the rationale for their inclusion is thoroughly explained. If acceptable, the indices should be incorporated as the final step of the mathematical approach previously described (i.e., multiply Habitat Equivalent Units by the condition index).

2.5 Summary

The approach outlined in this document will be used in quantifying the HADD of fish habitat. It may also be used to assist in addressing fish habitat compensation necessary to ensure *No Net Loss* of productive fish habitat.

Of the 244,765 m^2 of habitat identified in Lake X, a range of 87,824 to 244,765 m^2 (or 36% - 100% of the total available habitat) has been identified as preferred habitat for the species in question (i.e., brook trout, Atlantic salmon, brown trout, rainbow smelt, threespine stickleback and American eel) that will be impacted as a result of tailings deposition.

As part of the Department's HADD determination process, this measurement of habitat will be considered within the context of other information sources, including fisheries resources, fisheries management plans, local and/or traditional ecological knowledge, critical or limiting habitats, etc.

Table 2.9: Habitat Equivalent Units for each individual fish species present within the lake. These units were calculated using the Habitat Suitability Indices reported in Table 2.8 and surface areas of available lake habitat types listed in Table 2.2.

	Littoral Zone						**Non-littoral Zone**			
Species	Coarse/No Vegetation (11,279 m^2)	Medium/No Vegetation (60,195 m^2)	Fine/No Vegetation (142,273 m^2)	Coarse/Vegetation (465 m^2)	Medium/Vegetation (8,348 m^2)	Fine/Vegetation (9,885 m^2)	Coarse/Pelagic (0 m^2)	Medium/Pelagic (0 m^2)	Fine/Pelagic (12,320 m^2)	Total Available Habitat (244,765 m^2)
brook trout	11,279	60,195	108,127	465	8,348	7,513	NA	NA	2,094	198,021
Atlantic salmon	11,279	55,379	48,373	465	7,012	3,361	NA	NA	3,080	128,949
brown trout	11,279	60,195	59,755	363	8,348	3,361	NA	NA	7,269	150,570
rainbow smelt	11,279	60,195	142,273	465	8,348	9,885	NA	NA	12,320	244,765
threespine stickleback	0	40,331	142,273	0	6,511	8,798	NA	NA	12,320	210,233
American eel	11,279	0	71,137	465	0	4,943	NA	NA	0	87,824

2.6 Partial Lake Destruction

The following criteria apply specifically to situations where only a portion of a lake is being negatively impacted. Firstly, the impacted area should be treated in the same manner as described previously for the whole lake destruction example. Secondly, the portion of the lake that is not directly impacted by the proposed project will also need to be considered. Depending on the size of the lake in question, two approaches are recommended. For lakes ≤200 ha, the entire lake should be sampled in the same manner as described for whole lake destruction, and for lakes > 200 ha, 30% of the unimpacted lake area (i.e., excluding the area of the lake being impacted) should be randomly sampled. This is necessary in order to determine whether habitat within the proposed area of impact which will be altered, disrupted or destroyed is also present within other remaining areas of the lake ecosystem.

3.0 ACKNOWLEDGEMENTS

The authors would like to thank M. O'Connell, K. Clarke, D. Scruton, S. Snow, L. Park, J. Meade and M. Barnes of DFO and B. LeDrew of AMEC Earth & Environmental Limited for their participation in workshops and/or technical review. R. Burton is acknowledged for development of a spreadsheet program to assist in performing the actual calculations outlined in this document. Thanks are also given to J. Kelly and N. Ollerhead for assistance with figure production. Special thanks to K. Minns, DFO, Central and Arctic, for ongoing interest and support in initiating a lacustrine habitat classification system. Many thanks also to the external reviewers of this document who are too numerous to mention.

4.0 REFERENCES

Bradbury, C., M.M. Roberge and C.K. Minns. 1999. Life history characteristics of freshwater fishes occurring in Newfoundland and Labrador, with major emphasis on lake habitat characteristics. Can. MS Rep. Fish. Aquat. Sci. 2485: vii + 150p.

Coutant, C.C. 1977. Compilation of temperature preference data. J. Fish. Res. Board Can. 34: 739-745.

Devries, D.R. and R.V. Frie. 1996. Determination of age and growth, p. 483-512 *In:* B.R. Murphy and D.W. Willis (eds.). Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Fisheries and Oceans Canada. 1986. The Department of Fisheries and Oceans policy for the management of fish habitat. Fisheries and Oceans, Ottawa, DFO/4486, 28p.

Fisheries and Oceans Canada. 1998a. Decision framework for the determination and authorization of harmful alteration, disruption or destruction of fish habitat, Fisheries and Oceans, Ottawa, DFO/5531, 22 p.

Fisheries and Oceans Canada. 1998b. Habitat conservation and protection guidelines, Second Edition. Fisheries and Oceans, Ottawa, DFO/5859.

Fry, F.E.J. 1971. The effect of environmental factors on the physiology of fish, p. 1-98 *In:* W.S.Hoar and D.J. Randall (eds.). Inland Fisheries Management in North America. American Fisheries Society, Bethesda, Maryland.

Hammar, J. and O. Filipsson. 1985. Ecological testfishing with the Lundgren gillnets of multiple mesh size: the Drottningholm technique modified for Newfoundland Arctic char populations. Rep. Inst. Freshw. Res., Drottningholm 62: 12-35.

Minns, C.K. 1995. Calculating net change of productivity of fish habitats. Can. MS Rep. Fish. Aquat. Sci. 2282: vi + 37p.

Minns, C.K. 1997. Quantifying 'no net loss' of productivity of fish habitats. Can. J. Fish. Aquat. Sci. 54: 2463-2473.

Minns, C.K. and D.A. Hurley. 1988. Effects of net length and set time on fish catches in gillnets. North Am. J. Fish. Mgmt. 8: 216-223.

Minns, C.K. and R.B. Nairn. 1999. Defensible methods: applications of a procedure for assessing developments affecting littoral fish habitat on the lower Great Lakes, p. 15-35 *In:* T.P. Murphy and M. Munawar (eds.). Aquatic Restoration in Canada. Backhuys Publishers, The Netherlands, 211p.

Minns, C.K., J.D. Meisner, J.E. Moore, L.A. Greig and R.G. Randall. 1995. Defensible methods for pre- and post-development assessment of fish habitat in the Great Lakes. I. A prototype methodology for headlands and offshore structures. Can. MS Rep. Fish. Aquat. Sci. 2328: xiii + 65p.

Richards, L.J. and J.-J. Maguire. 1998. Recent international agreements and the precautionary approach: new directions for fisheries management science. Can. J. Fish. Aquat. Sci. 55: 1545-1552.

Scruton, D.A., T.C. Anderson, C.E. Bourgeois and J.P. O'Brien. 1992. Small stream surveys for public sponsored habitat improvement and enhancement projects. Can. MS Rep. Fish. Aquat. Sci. No. 2163: v + 49p.

Sooley, D.R., E.A. Luiker and M.A. Barnes. 1998. Standard methods guide for freshwater fish and fish habitat surveys in Newfoundland and Labrador: rivers and streams. Fisheries and Oceans, St. John's, NF. iii + 50p.

Terrell, J.W., T.E. McMahon, P.D. Inskip, R.F. Raleigh and K.L. Williamson. 1982. Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the habitat evaluation procedures. U.S. Fish and Wild. Serv. FWS/OBS-82/10.A: 54p.

Wetzel, R.G. 1983. Limnology, Second Edition. Saunders College Publishing. xii + 767p.

Appendix A - Glossary of Terms

Angling – Method of fish sampling that involves the use of a rod and reel.

Adults – Fish that have reached sexual maturity and are able to reproduce, but are not in spawning condition.

Anadromous – Fish which breed in freshwater but spend varying portions of their adult life at sea; also commonly referred to as sea-run.

Aquatic – Living in or near water.

Aquatic Plants – Plants bearing photosynthetically active parts that are permanently, or at least for several months of the year, submerged in fresh water.

Bank Stability – The degree of erosion on shoreline banks caused by natural forces or human activity. It is generally reported as a percentage of the area surveyed which contains stable banks (i.e., if there is no bank erosion, bank stability is given a rating of 100%; if 20% of the bank is eroding, bank stability is given a rating of 80%).

Bathymetry – The systematic measuring of water depths in lakes.

Beach Seine – In its simplest form, the beach seine is made up of mesh of uniform size and consists of two wings and a bunt section in the center that holds the catch. Beach seines are used to actively trap fish by surrounding them in a fence-like wall of netting and are typically used in shallow water over relatively smooth bottoms. Thus, beach seines are generally most effective at capturing near shore residents or species that concentrate near shore on a daily or seasonal basis.

Benchmark – A permanent object of known elevation, such as a prominent tree, large boulder or bedrock outcrop along the shoreline of a lake that is used to assess water level at various times throughout the year.

Benthic – Pertaining to the bottom region of a lake.

Benthic Organisms – Individuals living in or on the bottom (e.g., inhabiting sediments, woody debris, aquatic plants, etc.) of a body of water for at least part of their life cycle and are dependent upon the decomposition cycle for most, if not all, of its basic food supply.

Catadromous – Fish which migrate to sea to spawn but spend most of their life in freshwater.

Catch-per-unit-effort (CPUE) – The number of fish caught per unit of time or area and is often used as an estimate of relative fish abundance.

Condition Indices – Indirect measures of lake condition used to provide additional information on the quality of fish habitat (e.g., nutrient availability, water quality, morphometry, presence of contaminants, etc.).

Contour Map – A graphic representation of the lake bottom as determined from depth soundings and is sometimes referred to as a bathymetric chart.

Cover - Features within (or in close proximity to) the aquatic environment that may be used by fish for protection/refuge from predators, competitors and adverse environmental conditions (e.g., aquatic vegetation, rocky substrate, woody debris, etc.).

Critical Habitat – Habitat that is essential for the continued survival of a species.

Depositional – Characteristic of lower energy sites in which current velocity and turbulence are insufficient to carry away finer organic and/or inorganic particles which, therefore, accumulate on the lake bottom.

Depth – Vertical distance from the bottom of the lake to the water surface.

Electrical Thermometer – A thermometer that measures temperature remotely by cable and thermistor probe.

Emergent Vegetation - Aquatic plants growing above or extending above the water surface (e.g., cattails, sedges, grasses, rushes, etc.).

Experimental Gillnet – A monofilament net which consists of multiple panels, each of a different mesh size, that are strung together. Fish are captured when the maxillary or opercular area is caught in the mesh when the fish encounters the net. However, fish may also become entangled by their teeth, spines, girth or scales as they attempt to pass through the net or free themselves.

Fin Ray – An articulated or jointed rod that supports the membrane of a fin; structure used for aging certain fish species (e.g., longnose and white suckers).

Fish – Includes finfish, shellfish, crustaceans, marine animals and the eggs, sperm, spat, larvae and juvenile stages of finfish, shellfish, crustaceans and marine animals.

Fish Habitat – Spawning, nursery, rearing, food supply, over-wintering and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes.

Fyke Net – Type of net that consists of an internal cone and is often fitted with wings to direct the movement of fish into the cone section. The use of fyke nets are usually restricted to near shore or shallow areas of a lake not much deeper than the height of the net.

Gillnet – A monofilament net consisting of a single mesh size (see also experimental gillnet). Generally set in shallow water areas of lakes; however, bottom sets are possible at depths exceeding 50 m. Gillnet sampling is usually limited to areas free of obstructions, snags and floating debris as well as locations with little or no current.

Guild - A group of species that have similar habitat and/or life history requirements.

Habitat Equivalent Units – A relative measure of fish habitat productivity that is a product of bottom surface area and its suitability (or utilization) by all life stages of a particular species.

HADD – A harmful alteration, disruption or destruction of fish habitat which reduces its capacity to support one or more life processes of fish.

***In situ* Cover** – Includes rocky substrates and submerged woody debris (e.g., logs, tree roots, etc.) that are used by fish for refuge.

Invertebrates – Collective term used for all animals without a backbone or spinal cord.

Juveniles - Fish older than one year of age and not sexually mature.

Lacustrine – Pertaining to lakes or ponds.

Life Cycle – The various phases an individual passes through from birth to maturity and reproduction.

Life Stage – An extended period during the life cycle of an organism that is characterized by little or no change in development (e.g., egg, larval, fry, juvenile, adult, etc.).

Limnology – The study of fresh waters, including biological, geological, physical and chemical aspects.

Littoral Zone - The shallow, near shore region of a lake where adequate light can penetrate to the lake bottom to allow for the growth of rooted aquatic plants. These peripheral areas are subject to fluctuating water temperatures, water levels and erosion of onshore materials through wave action and the grinding of ice.

Littoriprofundal Zone – A transitional area below the littoral zone that is occupied by scattered photosynthetic algae and bacteria.

Lundgren Experimental Gillnets – There are two types of Lundgren nets, a benthic and a pelagic. The materials in both nets consist of transparent monofilament nylon and contain multiple panels of variable mesh size.

Lundgren Benthic Gillnets – A monofilament net, 1.5 m deep and composed of twelve 3.0 m panels of variable mesh sizes (stretched mesh sizes range from 3/4 inch to 6 inch). The order of the panels is such that the larger mesh sizes are surrounded by smaller ones. A revised benthic net contains two additional panels with finer mesh sizes (stretched mesh of 1/2 and 5/16 inch). For information on the ordering of these panels refer to Hammar and Filipsson (1985).

Lundgren Pelagic Gillnets – These nets consist of the same mesh sizes and materials as the benthic nets except the nets are 6 m deep with each panel being 6 m long. The different panels are arranged in order of increasing mesh size.

Macrophytes – Algae and rooted aquatic plants that can be seen with the naked eye.

Mitigation – Measures taken to avoid or minimize adverse impacts on fish and fish habitat (e.g., project relocation or redesign, reschedule timing of project, maintaining fish passage, siltation control, etc.).

Morphometry – Relates to the various physical dimensions of a lake including depth, volume, surface area, etc.

Non-littoral Zone – The region of a lake that extends beyond the outer limit of the littoral zone and includes littoriprofundal and profundal zones. It is generally characterized by decay rather than production of organic matter. The substrates within this region are usually soft and offer little in the way of habitat diversity.

Nursey (or Rearing) Habitat – Fish habitat which provides food and cover for immature fish.

Otolith – Inner ear bones (three pairs) found in bony fishes; the Sagittae is the most commonly used ear bone for aging fish.

Overhead Cover – Includes riparian vegetation overhanging the littoral zone, undercut banks and woody debris at the surface of the water.

Pelagic Zone – Refers to open-water regions of the lake that are not directly influenced by the shore or the bottom; plankton and pelagic fish inhabit this region.

Profundal Zone – The zone below which light penetration is inadequate for plant growth.

Riparian Vegetation – Mature trees, alders, shrubs, grasses, etc. bordering along the perimeter of a lake or pond.

Secchi Depth – The greatest distance from the surface of the water at which a Secchi disc can be visually detected. It provides a reasonable approximation of the extent of light penetration and hence is commonly used to determine the extent of the littoral zone.

Secchi Disc – A weighted disc, with four alternating black and white quadrants, and a calibrated line attached to the center which is lowered into the water to measure the transparency or clarity of the water on the basis of visibility; it therefore measures the approximate depth of the photic zone.

Spawning – Fish that are in spawning condition.

Spawning Habitat – Various substrates, vegetation, woody debris, etc. used by fish for egg deposition during spawning and includes the incubation of fertilized eggs.

Submergent Vegetation – Aquatic plants that grow entirely below the water surface (e.g., elodea, bladderwort, pipewort, potamogeton, etc.).

Substrate – The materials that comprise the lake bottom including; bedrock, boulder, rubble, cobble, gravel, sand, silt, clay and detritus.

Thermal Stratification – Arrangement of water masses into separate, distinct horizontal layers as a result of differences in density caused by changes in temperature.

Thermocline – The layer in a thermally stratified body of water where water temperature decreases at a rate of more than 1°C for each meter of depth. During the summer, it is common for deep bodies of water to become thermally stratified into three distinct layers. The upper layer (epilimnion) is characterized by more or less uniform, warm and fairly turbulent water. The lower layer (hypolimnion) is deep, cold and relatively undisturbed water. Between these two layers, the metalimnion is a narrow layer having a steep thermal gradient marking the transition from the warmer, upper stratum to the lower, colder stratum.

Transect – A method of lake sampling whereby measurements are taken along a series of straight lines that are typically set up perpendicular to the shoreline.

Turbidity – A condition of reduced transparency caused by suspended particles such as silt, clay, organic and inorganic matter, plankton and other microscopic organisms in water.

Trophic State – The productivity status of a body of water (e.g., oligotrophic lakes are relatively low in nutrients and usually low in productivity, while eutrophic lakes are relatively rich in nutrients and are usually highly productive).

Turnover – Vertical mixing of layers in a body of water usually brought about by seasonal changes in temperature and high winds; usually occurs in spring and/or fall in the temperate zone. Uniform physical and chemical properties are the result of the change.

Upwelling Groundwater – Water present below the surface of the ground that percolates up through the substrate. It appears to be an important determinant for brook trout spawning in most geographic areas and may also play a role in over-wintering survival of certain species.

Wire Cage Traps – Traps of wire construction that are usually cylindrical in shape and have funnel entrances at both ends. These traps are available in a variety of sizes and are typically used for sampling juveniles and small fish in bottom regions of lakes.

Young-of-the-Year (YOY) - Fish that are under one year of age.

Appendix B – Field methodologies

Introduction

It is important to note that although the survey methods outlined in this document are recommended by the DFO, they are intended only as a guideline. These data collection standards may be refined by other scientifically sound survey methods as they become available through advances in research and/or improvements in technology. Any proponent wishing to introduce other survey equipment and techniques, however, should consult with the DFO prior to doing so to ensure that the proposed sampling equipment and methods are appropriate for the study area in question and the data required.

In addition, it should be noted that the type and extent of data collection may vary depending on project and site specific conditions. Some of the sampling and surveying methodologies outlined below may provide information useful in the interpretation of habitat requirements information contained in Bradbury et al. (1999).

Where possible, it is recommended that lake habitat surveys be conducted during late summer since maximum stratification typically occurs at this time.

Lake Morphometry

The methods of measuring and analyzing the physical dimensions of a lake are termed morphometry. Morphological characteristics, such as lake volume, surface area, maximum depth, mean depth and shoreline development index (SDI), have a significant effect on nearly all major physical, chemical and biological processes in lakes. For this reason, development of a bathymetric map depicting depth contours, shape of the shoreline, and locations of inflows and/or outflows is an important first step in the classification/quantification of available lake habitat.

Maximum depth is simply the greatest depth recorded within a given lake, while the mean depth is calculated by dividing the volume of the lake by the surface area with both characteristics being measured in the same units. It is recommended that separate surface areas and volume estimates be calculated for both the littoral and non-littoral zones. The SDI is a measure of the shape of a lake and can be indicative of the amount of littoral zone present. SDI is a comparative figure relating the shoreline length to the circumference of a circle having the same area as the lake and thus is an index of the regularity of the shoreline. It can be calculated using the following formula:

$$SDI = L / 2 (A)^{1/2},$$

where L = length of the shoreline and A = surface area of the lake. It follows logically that a perfectly circular lake would have a SDI equal to 1.0 (i.e., the smallest possible index) and the greater the irregularity of the shoreline, the greater the SDI.

Water Chemistry

Water chemistry assessments may involve a variety of different parameters such as nutrient sources (e.g., phosphorus, nitrogen, Total Dissolved Solids (TDS)), other measures of water quality (e.g., turbidity, Secchi depth, dissolved oxygen, pH), the presence of contaminants (e.g., mercury, cadmium) and so on.

The selection of water chemistry stations should reflect as much as possible overall lake conditions. Therefore, in order to obtain representative samples, sites should be chosen to include the widest possible variety of different habitat types (i.e., various depths, near lake inflows and outflows, within bays that are isolated from the main body of water, etc.).

Nutrient availability is often used as a determinant (or index) of lake trophic status. For example, since phosphorus is an essential plant nutrient, it may be a limiting factor for plant growth and hence productivity. Due to its highly dynamic state, the best value for quantifying phosphorus in lakes is total phosphorus.

A ratio of TDS (which provides an indication of the amount of nutrient influx into lakes) to the mean depth of a lake (which provides an indication of lake morphometry), commonly referred to as the Morphoedaphic Index (MEI), may also be used as an indicator of potential lake productivity. MEI is calculated using the following equation:

$$\mathbf{MEI = \sqrt{TDS}/Mean\ Depth}$$

Secchi Depth

In classifying lacustrine habitat, it is generally necessary to divide the lake into a littoral and non-littoral zone. A reasonable approximation of the extent of light penetration and hence the littoral zone may be obtained by measuring the Secchi depth. This estimate may be supplemented with information regarding the outer limit or boundary of plant growth and/or a delineation of the mud zone (i.e., transition between coarse and soft or flocculent substrate types).

A Secchi disc consists of a weighted circular disc (usually ranging in diameter from 20-25 cm for limnological studies), with four alternating black and white quadrants. (Additional weight may be required to ensure a vertical trajectory depending on site specific conditions such as water currents and wind). The disc is attached to a calibrated line (0.5-meter increments) by a ring at the center so that it hangs horizontally when held by the line. Secchi depth measurements should be conducted near the central or deepest part of the lake, away from any inflows. To standardize the Secchi depth measure, the disc should always be lowered into the water over the shaded side of a boat between 10:00 – 14:00 hrs. The depth at which the disc disappears should be noted. The disc should be lowered a little further and then slowly raised until it reappears. This depth should also be noted. The average of the two depth readings is the Secchi depth. It is important to note that sunglasses should not be worn when taking these measurements.

Since surface conditions (e.g., rippled, wavy or rough) alter Secchi depth readings, such measurements should only be taken under calm surface conditions and should not be performed after a storm event or adverse environmental conditions since these events can reduce water transparency and hence Secchi depth. For similar reasons, sampling during spring or fall turnover should also be avoided. When taking Secchi depth readings it is important that water surface condition, cloud cover and time of day be recorded. An estimation of cloud cover should be reported as a percentage of the total sky. For example, a clear sky is indicated as 0% cover.

Water Temperature

Water temperature is one of the most important factors in determining habitat quality for fish survival and production. In particular, many fish species have distinct thermal optima (Coutant 1977) and limits (Fry 1971), such that a seasonal absence of suitable temperatures can limit the success of a species or even exclude it entirely. Water temperature can also have an important influence on fish distribution and abundance. For example, in thermally stratified lakes, many coldwater fish move offshore and inhabit areas beneath the thermocline as water temperatures increase during the summer. Often times these fish do not return to near shore areas until after the fall turnover, when there is a uniform temperature throughout the water column.

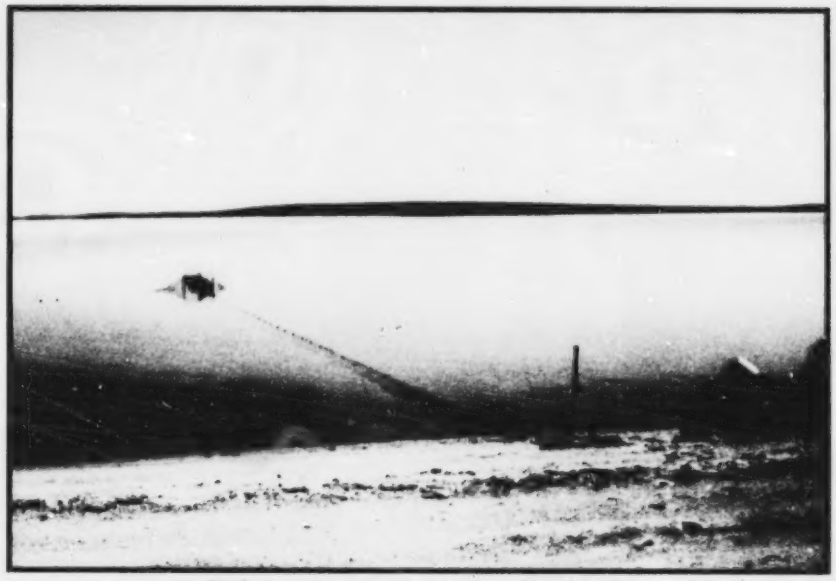
Wind and wave action affect the mixing or circulation of water. As summer progresses, water temperatures increase and resistance to vertical mixing becomes more pronounced at which time a condition known as thermal stratification may be evident in deeper lakes. At a very minimum, when conducting fish habitat surveys, vertical temperature profiles should be taken in the same general area as Secchi depth readings (i.e., at or near the deepest point in the lake). Since water temperature profiles can be accurately and rapidly collected using electrical thermometers (that are relatively inexpensive), water temperatures should be taken at the surface and at one-meter intervals throughout the water column until the bottom of the lake is reached. This will allow the detection of a thermocline, if one is present. If the water depth is > 30 m, it is recommended that water temperatures be taken at one meter intervals throughout the thermocline as well as at mid-depth and bottom.

Bathymetry

A bathymetric survey is essential to develop the profile characteristics of a lake and to calculate the volume of water as well as area. Information collected during a bathymetric survey should be plotted on a map, referred to as a contour map or bathymetric chart, that is basically a graphic representation of the lake bottom, as determined from depth soundings.

The first step in conducting a bathymetric survey is to obtain an outline map of the lake. This map may be obtained from aerial photographs or topographical maps and should be of sufficient scale for recording all necessary survey information. It is recommended that the accuracy of these maps be ground truthed.

In conducting a bathymetric survey, continuous depth profiles are collected across a lake by moving a depth sounder, typically mounted below the water line at the stern of a boat, along various transects at a constant speed. The frequency of depth soundings and number of transects required depends on how rapidly the depth is changing. In areas where depth changes markedly, additional transects with more measurements per transect may be required. In general, transects should be close enough together to eliminate guesswork during final mapping. Obviously, the more transects, the more reliably the depth contours can be mapped. Transects should be roughly parallel to one another, and as close to perpendicular to shore as possible. Start and end points of a transect can be lined up through the use of prominent landmarks or by marking shoreline features with flagging tape.



Fyke nets are set perpendicular to the shoreline during fish sampling.

Conducting a bathymetric survey along a predetermined transect.

It is recommended that depth contours be constructed at 1-m intervals within the littoral zone. For survey work conducted in the non-littoral zone, depth contours should be constructed every 2 m for lakes with a maximum depth of 10 m and every 5 m for lakes with a maximum depth > 10 m. It is important to note that depth contours should at least be contiguous with the depth categories reported in Bradbury et al. (1999). Similar contours are also recommended when collecting information on bottom substrates and cover which will be discussed later.

Depth soundings, using an electronic depth sounder, should be taken as close to shore as possible and in cases where transects either start or end some distance from shore, the distance from shore and the depth must be estimated or measured manually. When surveying along a transect, the boat should be operated at a constant speed. As a general rule of thumb, a speed of 3.5 km/hr is usually optimum, however, this speed will depend on ambient wind and weather conditions since boat speed must be sufficiently fast to maintain control and direction. It is important that depths obtained from the depth sounder are checked frequently throughout the survey to ensure proper readings. For example, a paddle with marked graduations or a sufficiently weighted, calibrated rope are useful tools for verifying sounding in lakes. The depth data collected can then be plotted along the transects on the outline map, and contour lines of equal depth connected by interpolation. This process of interpolation can be easily and accurately accomplished through the use of various computer software programs.

A benchmark (i.e., permanent object such as a prominent tree, large boulder or bedrock outcrop along the shoreline of the lake that is located above the high water mark) should be established to assess the water level of the lake at the time of the survey. This is important since water levels are subject to natural seasonal variations as well as alterations by human activities. The benchmark should be photographed and permanently marked for future reference.

An estimate of the normal high water level of the lake should be provided. This may be based on shoreline erosion, growth of moss or lichen on large boulders and bedrock, deposition of woody debris, etc. The approximate difference between this level and that at the time of the survey should also be measured and reported. Any areas that are routinely inundated on a seasonal basis should be considered fish habitat and included in the habitat quantification process since some species may utilize this habitat (e.g., northern pike use inundated vegetation during spawning, rearing and adult foraging).

The locations of all tributaries flowing into or out of the lake should be reported, including their flow status (dry, low, moderate or high). The following information should also be collected for at least the lowermost 50 m of each tributary following methods outlined in Scruton et al. (1992); average depth, average width, surface velocity, substrate composition, cover, riparian vegetation, stream bank stability and any obstructions to fish passage.

Substrate Mapping

Substrate composition determines the quality of spawning and rearing habitat and available cover for many fish and also influences the production of benthic invertebrates. A common method for estimating substrate composition is to classify substrate visually according to particle size and report as a proportion (or percentage) of the area surveyed. The following substrate classifications have been adapted from Sooley et al. (1998):

Bedrock - continuous solid rock exposed by scouring forces.

Boulder - rocks greater than 25 cm in diameter.

Rubble - large rocks 14-25 cm in diameter.

Cobble - moderate to small-sized rocks 3-13 cm in diameter.

Gravel - small stones between 2 mm-3cm in diameter.

Sand - fine deposits frequently found on margins of streams or between rocks and stones, ranging from 0.06-2.0 mm in diameter.

Silt - very fine deposits less than 0.06 mm in diameter, that can be carried or moved by current and deposited in slower moving water.

Muck - a soft material composed of silt and clay and containing 85% or more organic materials such as leaves, decayed aquatic plants, etc.

Clay - a material of inorganic origin with a greasy feel between the fingers and no apparent structure.

In clear, shallow waters, aerial photographs may assist in determining the distribution and abundance of various substrate types; however, this method will require some level of ground truthing.

If the lake bottom is clearly visible from the surface then a helicopter may be used to collect substrate data. This is particularly useful when conducting surveys of larger, more remote systems. For smaller systems, substrate data may be collected by simply looking over the shaded side of a boat (at which time an underwater viewer may be used to increase visibility) or by snorkeling. It should be noted, however, that unless the water is very transparent, direct visual observations from the surface of the water will be limited to shallow water. At increasing depths, visual assessments may be supplemented with SCUBA diving, underwater video, grab/sediment sampling, or through the use of electronic devices (e.g., echo sounders, sonar, multi-beam acoustics) that infer the relative hardness (muck vs bedrock) of substrates in lakes.

As outlined previously, the contours used for substrate mapping should be similar to those employed during the bathymetric survey. Since substrate data will be recorded along transects, the same as bathymetric data, some degree of interpolation will be required. From this information a detailed map of the spatial distribution of the various substrate types should be constructed. An estimate of the bottom area encompassed by each of the nine substrate types, if available, should be recorded for each depth category reported in Bradbury et al. (1999) (e.g., 0-1 m, 1-2 m, 2-5 m, 5-10 m and 10+ m). This may be further summarized by each of the main substrate categories (e.g., Littoral Fine, Littoral Medium, Littoral Coarse, Non-Littoral Fine, Non-Littoral Medium and Non-Littoral Coarse). It should be noted, however, that since the non-littoral zone is typically comprised of mainly fine substrates, a single category may be appropriate for this region of the lake (e.g., Non-Littoral Fine).

Cover

Cover is defined as features within (or in close proximity to) the aquatic environment that may be used by fish for protection/refuge from predators, competitors and adverse environmental conditions. In lakes, cover may be broken down into four main categories:

i) Emergent vegetation – aquatic plants growing above or extending above the water surface (e.g., cattails, sedges, grasses, rushes).

ii) Submergent vegetation – aquatic plants that grow entirely below the water surface (e.g., elodea, bladderwort, pipewort, potamogeton).

iii) Overhead – Includes riparian vegetation overhanging the littoral zone, undercut banks and woody debris at the surface of the water.

iv) In situ – Includes rocky substrate and submerged woody debris (e.g., logs, tree roots, etc.).

It is important to note that although Bradbury et al. (1999) contains information on utilization of all four cover types outlined above, for the purposes of this document, reporting should be limited to aquatic vegetation. Aquatic plants are an important component of fish habitat since they provide spawning, nursery (or refuge) and feeding areas for many fish species. Aquatic vegetation also helps stabilize the lake bottom and shoreline thereby reducing erosion and subsequent increases in siltation. In any water body, colonization by plants within a given area will depend to a large extent on whether it is protected from or exposed to strong turbulence. For instance, bare rock and gravel areas are usually associated with strong currents, having little or no vegetation. However, areas containing fine substrates are generally associated with sedimentation and little or no turbulence which is typically conducive to plant growth.

For ease of data collection, aquatic vegetation may be reported as either emergent or submergent vegetation and although species identification is not required, it is not discouraged either. Areas containing aquatic vegetation should be delineated and plotted on a map. An estimate of the bottom area occupied by aquatic plants should also be provided for each depth and substrate category reported in Bradbury et al. (1999), where applicable (e.g., 0-1 m, 1-2 m, 2-5 m, 5-10 m and 10+ m).

Vegetation may be measured along a transect concomitantly with other measurements such as substrate and depth. The timing of such surveys, however, is extremely important since considerable variability may exist in vegetative growth patterns depending on season. Similar to substrate mapping, in shallow waters aerial photographs may be used to record the distribution of aquatic plants providing plant distributions are later ground truthed in the field.

One of the main strengths of the above field methodology is its reliance on physical habitat data which is relatively easy to sample and more constant over time than biological data. The physical habitat features, such as substrate and depth, are relatively constant, while the amount and type of aquatic vegetation usually exhibits only moderate variation.

Fish Sampling

Prior to conducting any fish sampling, an experimental license must be obtained from the regulatory agency or governing body (i.e., DFO in the case of inland waters in Newfoundland and Labrador). The license request must identify all fish sampling requirements including the types of sampling gear to be used, sampling period and location, fish species targeted, personnel involved and general purpose of the survey. This request should be submitted to the DFO well in advance of scheduled field activities (a minimum of one month) to allow adequate time for processing. During sampling emphasis should be placed on minimizing the number of fish dead sampled.

In order to obtain representative samples of all length/age classes and species of fish inhabiting lakes, a range of different gear types (i.e., fyke nets, experimental gillnets, Lundgren experimental gillnets, beach seines, wire cage traps, angling, etc.) are usually utilized. This is due to the fact that nearly all gear types are selective in the species and size of fish they capture. The capture success will also depend on where the gear is set. For example, in diverse fish assemblages, some species may be captured near the bottom, while others are captured predominantly in pelagic sets. Furthermore, fish may inhabit very different areas depending on the time of year and whether or not the lake exhibits thermal stratification. As outlined above, in thermally stratified lakes, many coldwater fish move offshore as water temperatures increase during the summer, mainly inhabiting areas below the thermocline. Therefore, to obtain representative samples of fish in lakes, sampling sites should be chosen to include the widest possible variety of different habitat types, which may include sites near lake inflows and outflows. Typically, prior knowledge of at least the general structure of the fish assemblage in the study area as well as their habitat requirements is essential for the selection of appropriate sampling gears and set specifications.

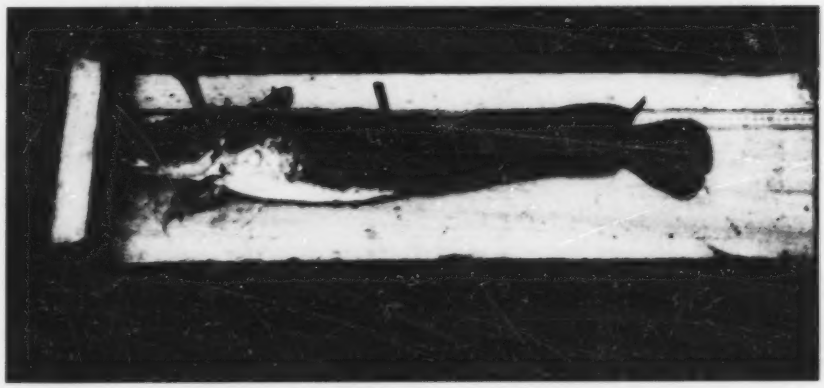
Capture efficiency, defined as the probability of retaining a certain species or size class using a particular sampling gear, may be influenced by a variety of factors. These factors include: time of day, season, water temperature, water depth, current velocity, substrate type, physical obstructions to the sampling gear, water clarity, fish morphology, etc. The length of time the gear is set can also influence sampling results

Experimental gillnets being set to sample fish species present within a lake.

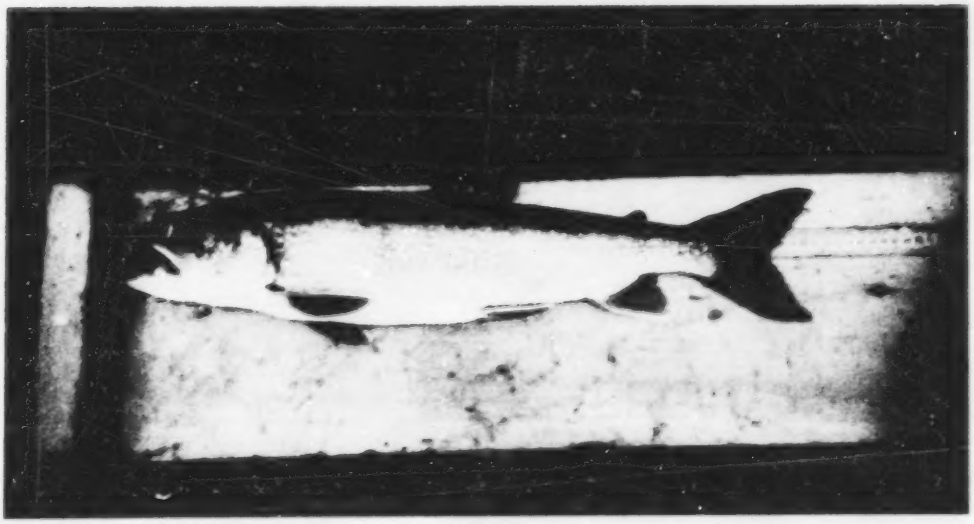
since catch rates are not necessarily constant over time. For example, gillnet capture efficiency decreases as fish accumulate in the net and it effectively becomes saturated (Minns and Hurley 1988). Given the myriad of factors that can influence catch-per-unit-effort (CPUE), the sampling, at the very least, should be standardized to cover the same time of day, water depth and substrate type. Since fish are normally more active and more readily available for collection during the twilight hours (i.e., dusk and dawn) than during daylight hours, most fishing gears are set during these periods of increased fish activity. Much of the variability among samples can be reduced through the use of rigidly defined sampling designs that specify the season, time, location and duration of net sets, coupled with precise gear (i.e., mesh sizes, net dimensions, etc.) and deployment specifications. This will help to ensure consistency and repeatability of the sampling program.

Retrieval of a fyke net set in the littoral zone of a lake.

An understanding of the general biological characteristics of existing fish communities, such as species composition, relative abundance, population length and age structure, is useful in determining potential habitat utilization within a given area. Once this information is known, Bradbury et al. (1999) should be consulted to obtain detailed information on the specific habitats that are required by the species present and their various life stages.



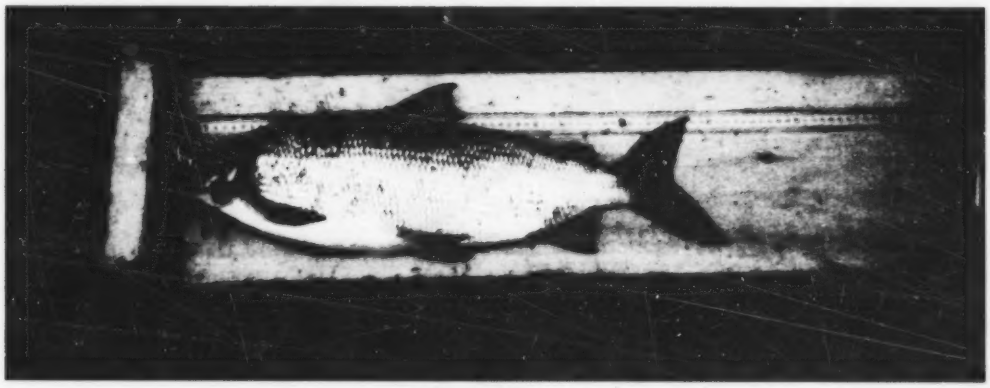
burbot



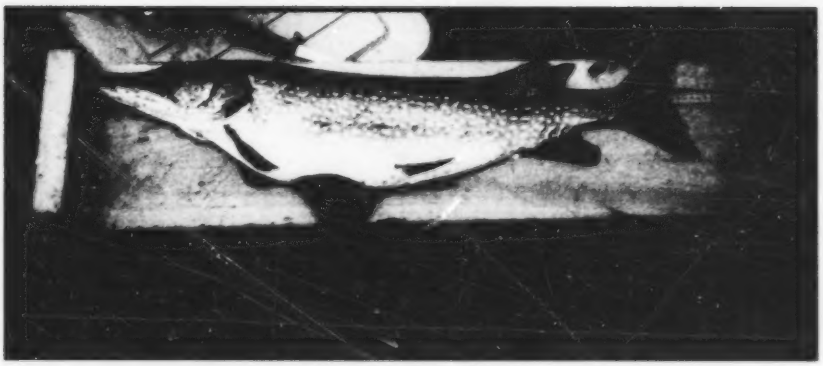
lake trout

Identifying various fisheries (e.g., existing or potential commercial, recreational and/or aboriginal fisheries) within the project area as well as their relative importance is also useful, especially when assigning values (or preferences) to various user groups. Potential sources of information may include consultation with various user groups, local DFO fishery officers or staff of DFO's Statistics Division, traditional ecological knowledge (TEK), consultant reports prepared for past developments, etc.

Examination of hard bony structures is the most frequently used method for aging fish. Structures used to age fish include scales, otoliths, fin rays, fin spines, cleithra, vertebrae, opercular bones and dentary bones. The basic underlying premise is that as fish grow they deposit minerals in these hard bony structures which appear as marks (or annuli), thereby producing characteristic growth patterns. The underlying mechanism for the formation of annual marks is related to changes in growth during alternating periods of relatively fast (e.g., spring and summer) and slow (e.g., fall and winter) growth. The choice of bony structure to be used for aging depends on characteristics of the species being sampled and geographic location. Information outlined in the following table may be used as a guide in determining the most suitable aging structure(s) for selected fish species. Detailed information on the techniques for the collection, storage and preparation of these various aging structures are outlined in Devries and Frie (1996).



lake whitefish



northern pike

Table B1. Preferred fish aging structures.

	Aging Structures				
Species	Otoliths	Scales	Fin	Cleithra	Opercular Bones
Atlantic salmon	2	1			
Arctic char	1	2			
brook trout	2	1			2
lake trout	1	2			
lake whitefish	1	2			
round whitefish	1	2			
northern pike		2		1	
burbot	1				2
longnose sucker			2		1
white sucker			2		1

1 = Primary structure (aging structure preferred by DFO staff in Newfoundland Region) and
2 = Secondary structure.